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(54) **ORGANIC LIGHT-EMITTING DIODE COMPRISING AMINE-BASED COMPOUNDS AND PYRENE-BASED COMPOUNDS**

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C09K 11/06 (2006.01)
H01L 51/50 (2006.01)

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CPC ***H01L 51/006*** (2013.01); ***C09K 11/06*** (2013.01); ***H01L 51/007*** (2013.01); ***H01L 51/0054*** (2013.01); *C09K 2211/188* (2013.01); *H01L 51/0081* (2013.01); *H01L 51/504* (2013.01); *H01L 51/5036* (2013.01); *H01L 2251/308* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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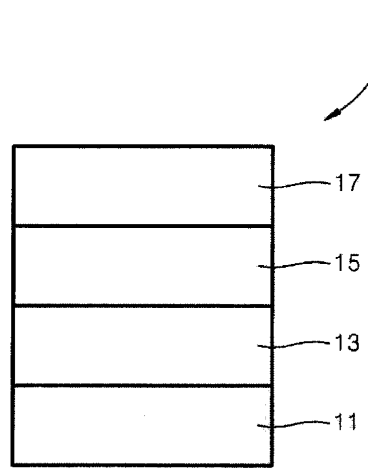
(57) **ABSTRACT**

An organic light-emitting diode includes a first electrode, a second electrode, and an organic layer disposed between the first electrode and the second electrode. The organic layer includes an emission layer. The organic layer also includes at least one amine-based compound and at least one pyrene-based compound. The organic layer may include a first emission layer and a second emission layer, and the amine-based compound may be in the first emission layer and the pyrene-based compound may be in the second emission layer.

5 Claims, 1 Drawing Sheet



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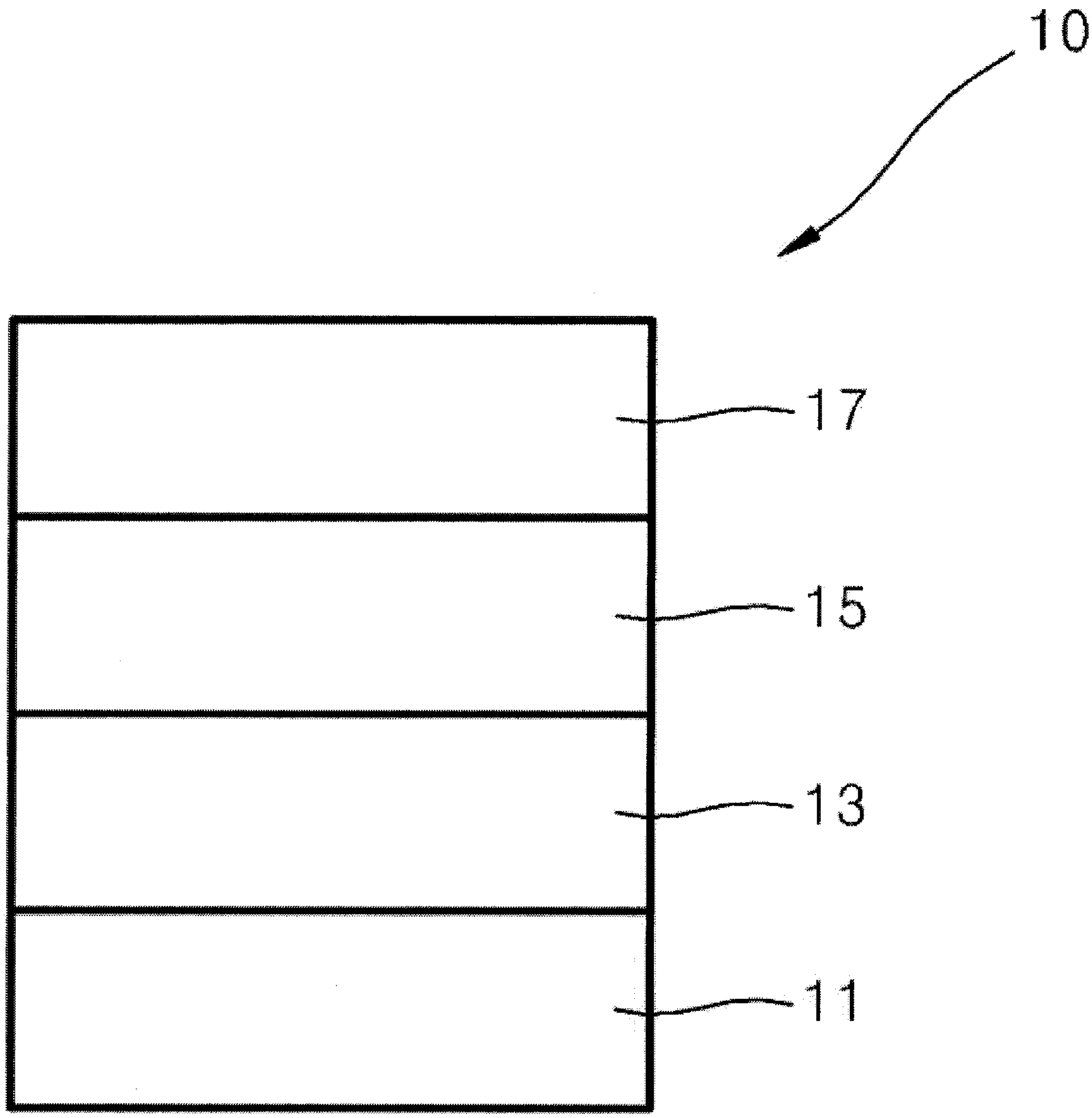
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ORGANIC LIGHT-EMITTING DIODE COMPRISING AMINE-BASED COMPOUNDS AND PYRENE-BASED COMPOUNDS

CROSS-REFERENCE TO RELATED PATENT APPLICATION

This application claims priority to and the benefit of Korean Patent Application No. 10-2013-0003513, filed on Jan. 11, 2013 in the Korean Intellectual Property Office, the entire content of which is incorporated herein by reference.

BACKGROUND

1. Technical Field

The present invention relates to organic light-emitting diodes comprising amine-based compounds and pyrene-based compounds.

2. Description of the Related Art

Organic light-emitting devices (OLEDs) are self-emitting devices that have advantages such as wide viewing angles, good contrast, quick response speeds, high brightness, and good driving voltage characteristics. Also, OLEDs can provide multicolored images.

A typical OLED has a structure including a substrate, and an anode, a hole transport layer (HTL), an emission layer (EML), an electron transport layer (ETL), and a cathode sequentially stacked on the substrate. In this regard, the HTL, the EML, and the ETL are organic thin films formed of organic compounds.

An operating principle of an OLED having the above-described structure is as follows:

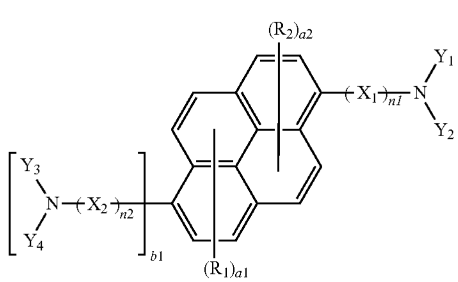
When a voltage is applied between the anode and the cathode, holes injected from the anode move to the EML via the HTL, and electrons injected from the cathode move to the EML via the ETL. The holes and electrons recombine in the EML to generate excitons. When the excitons drop from an excited state to a ground state, light is emitted.

SUMMARY OF THE INVENTION

Embodiments of the present invention are directed to a high definition organic light-emitting diode

According to another aspect of the present invention, an organic light-emitting device includes: a first electrode; a second electrode, and an organic layer between the first electrode and the second electrode and including an emission layer. The organic layer includes at least one amine-based compound represented by Formula 1 below and at least one pyrene-based compound represented by Formula 2 below.

<Formula 1>



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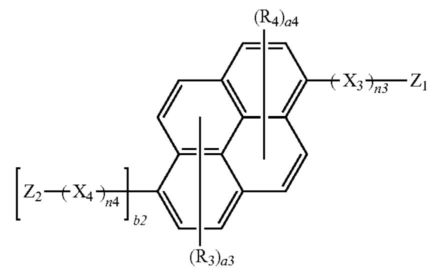
<Formula 2>



In Formula 1 and 2, X_1 to X_4 are each independently a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_2-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_2-C_{10} cycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, or a substituted or unsubstituted C_2-C_{60} heteroarylene group.

n1 to n4 are each independently an integer of 0 to 5. If n1 is an integer of 2 or more, then the 2 or more X_1 groups are the same or different, if n2 is an integer of 2 or more, then the 2 or more X_2 groups are the same or different, if n3 is an integer of 2 or more, then the 2 or more X_3 groups are the same or different, and if n4 is an integer of 2 or more, then the 2 or more X_4 groups are the same or different.

Y_1 to Y_4 are each independently a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-C_{10} cycloalkenyl group, a substituted or unsubstituted C_6-C_{30} aryl group, or a substituted or unsubstituted C_2-C_{30} heteroarylene group.

Z_1 and Z_2 are electron transporting groups and are each independently a substituted or unsubstituted C_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkenyl group, or a substituted or unsubstituted C_2-C_{60} heteroaryl group.

R_1 to R_4 are each independently a hydrogen atom, a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, or a substituted or unsubstituted C_2-C_{60} heteroaryl group.

a1 to a4 are each independently an integer of 0 to 4. If a1 is an integer of 2 or more, then the 2 or more R_1 groups are the same or different, if a2 is an integer of 2 or more, then the 2 or more R_2 groups are the same or different, if a3 is an integer of 2 or more, then the 2 or more R_3 groups are the same or different, and if a4 is an integer of 2 or more, then the 2 or more R_4 groups are the same or different.

b1 and b2 are each independently an integer of 0 or 1.

The organic light-emitting diode including the amine-based compound and the pyrene-based compound may have high efficiency and a long lifespan.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and advantages of the present invention will become more apparent by reference to the following detailed description, when considered in conjunction with the attached drawings in which:

FIG. **1** is a schematic view of a structure of an organic light-emitting diode according to an embodiment of the present invention.

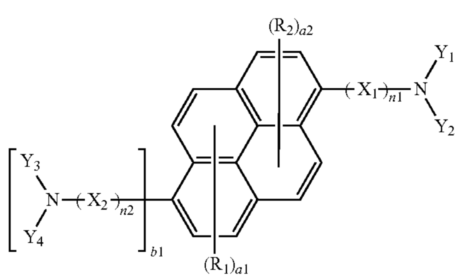
DETAILED DESCRIPTION OF THE INVENTION

In the present specification, the expression "organic layer includes at least one amine-based compound represented by Formula 1 and at least one pyrene-based compound represented by Formula 2" may be construed as "the organic layer includes one amine-based compound of Formula 1 or two different amine-based compounds of Formula 1, one pyrene-based compound of Formula 2 or two different pyrene-based compounds of Formula 2."

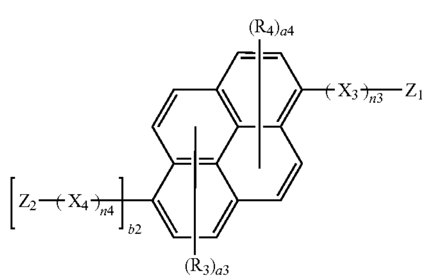
In the present specification, the term "organic layer" refers to a single layer and/or a plurality of layers between a first electrode and a second electrode.

An organic light-emitting diode includes a first electrode; a second electrode, and an organic layer between the first electrode and the second electrode. The organic layer includes an emission layer including at least one amine-based compound represented by Formula 1 below and at least one pyrene-based compound represented by Formula 2 below.

<Formula 1>



<Formula 2>



In Formulas 1 and 2, X_1 to X_4 are each independently a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_2-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_2-C_{10} cycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, or a substituted or unsubstituted C_2-C_{60} heteroarylene group.

n1 to n4 are each independently an integer of 0 to 5. If n1 is an integer of 2 or more, the 2 or more X_1 groups are the same or different, if n2 is an integer of 2 or more, the 2 or more X_2 groups are the same or different, if n3 is an integer of 2 or more, the 2 or more X_3 groups are the same or different, and if n4 is an integer of 2 or more, the 2 or more X_4 groups are the same or different.

Y_1 to Y_4 are each independently a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{30} aryl group, or a substituted or unsubstituted C_2-C_{30} heteroaryl group.

Z_1 and Z_2 are electron transporting groups and are each independently a substituted or unsubstituted C_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkenyl group, or a substituted or unsubstituted C_2-C_{60} heteroaryl group.

R_1 to R_4 are each independently selected from a hydrogen atom, a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, or a substituted or unsubstituted C_2-C_{60} heteroaryl group.

a1 to a4 are each independently an integer of 0 to 4. If a1 is an integer of 2 or more, the 2 or more R_1 groups are the same or different, if a2 is an integer of 2 or more, the 2 or more R_2 groups are the same or different, if a3 is an integer of 2 or more, the 2 or more R_3 groups are the same or different, and if a4 is an integer of 2 or more, the 2 or more R_4 groups are the same or different.

b1 and b2 are each independently an integer of 0 or 1.

According to an embodiment of the present invention, in Formulas 1 and 2, X_1 to X_4 may each independently be a substituted or unsubstituted C_3-C_{10} cycloalkylene group, a substituted or unsubstituted C_2-C_{10} heterocycloalkylene group, a substituted or unsubstituted C_3-C_{10} cycloalkenylene group, a substituted or unsubstituted C_2-C_{10} heterocycloalkenylene group, a substituted or unsubstituted C_6-C_{60} arylene group, or a substituted or unsubstituted C_2-C_{60} heteroarylene group, but X_1 to X_4 are not limited thereto.

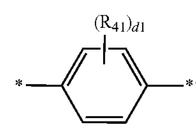
For example, in Formulas 1 and 2, X_1 to X_4 may each independently be a substituted or unsubstituted phenylene group, a substituted or unsubstituted pentalenylene group, a substituted or unsubstituted indenylene group, a substituted or unsubstituted naphthylene group, a substituted or unsubstituted azulenylene group, a substituted or unsubstituted heptalenylene group, a substituted or unsubstituted indacenylene group, a substituted or unsubstituted acenaphthylene group, a substituted or unsubstituted fluorenylene group, a substituted or unsubstituted phenalenylene group, a substituted or unsubstituted phenanthrenylene group, a substituted or unsubstituted anthrylene group, a substituted or unsubstituted fluoranthenylene group, a substituted or unsubstituted triphenylenylene group, a substituted or unsubstituted pyrenylene group, a substituted or unsubstituted chrysenylene group, a substituted or unsubstituted naphthacenylene group, a substituted or unsubstituted picenylene group, a substituted or unsubstituted perylenylene group, a substituted or unsubstituted pentaphenylene group, a substituted or unsubstituted hexacenylene group, a substituted or unsubstituted pyrrolylene group, a substituted or unsubstituted imidazolylene group, a substituted or unsubstituted pyrazolylene group, a substituted or unsubstituted pyridinylene group, a substituted or unsubstituted pyrazinylene group, a substituted or unsubstituted pyrimidinylene group, a substituted or unsubstituted pyridazinylene group, a substituted or unsubstituted isoindolylene group, a substituted or unsubstituted indolylene group, a substituted or unsubstituted indazolylene group, a substituted or unsubstituted indazolylene group, a substituted or unsubstituted purinylene group, a substituted or unsubstituted quinolinylene group, a substituted or unsubstituted benzoquinolinylene group, a substituted or unsubstituted phthalazinylene group, a substituted or unsubstituted naphthyridinylene group, a substituted or unsubstituted quinoxalinylene group, a substituted or unsubstituted quinazolinylene group, a substituted or unsubstituted cinnolinylene group, a substituted or unsubstituted carbazolylene group, a substituted or unsubstituted phenanthridinylene group, a substituted or unsubstituted acridinylene group, a substituted or unsubstituted phenanthrolinylene group, a substituted or unsubstituted phenazinylene group, a substituted or unsubstituted benzooxazolylene group, a substituted or unsubstituted benzoimidazolylene group, a substituted or unsubstituted furanylene group, a substituted or unsubstituted benzofuranylene group, a substituted or unsubstituted thiophenylene group, a substituted or unsubstituted benzothiophenylene group, a substituted or unsubstituted thiazolylene group, a substituted or unsubstituted isothiazolylene group, a substituted or unsubstituted benzothiazolylene group, a substituted or unsubstituted isoxazolylene group, a substituted or unsubstituted oxazolylene group, a substituted or unsubstituted triazolylene group, a substituted or unsubstituted tetrazolylene group, a substituted or unsubstituted oxadiazolylene group, a substituted or unsubstituted triazinylene group, a substituted or unsubstituted benzooxazolylene group, a substituted or unsubstituted dibenzopuranylene group, a substituted or unsubstituted dibenzothiophenylene group, or a substituted or unsubstituted benzocarbazolylene group, but X_1 to X_4 are not limited thereto.

For example, in Formulas 1 and 2, X_1 to X_4 may each independently be i) a phenylene group, a naphthylene group, an anthracenylene group, or a fluorenylene group; or ii) a phenylene group, a naphthylene group, an anthracenylene group, a fluorenylene group, or a C_1-C_{10} alkyl group; a C_1-C_{10} alkyl group substituted with at least one of a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof; a C_6-C_{16} aryl group or a C_2-C_{16} heteroaryl group; a C_6-C_{16} aryl group or a C_2-C_{16} heteroaryl group substituted with at least one of a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid or a salt thereof, a phosphoric acid or a salt thereof, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_6-C_{16} aryl group, or C_2-C_{16} heteroaryl group, but X_1 to X_4 are not limited thereto.

For example, in Formulas 1 and 2, X_1 to X_4 may each independently be selected from i) a phenylene group or a naphthylene group; ii) a phenylene group or a naphthylene group substituted with at least one of a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group; iii) a phenylene group or a naphthylene group substituted with at least one of a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group; an n-butyl group, an iso-butyl group, or a tert-butyl group; iv) a phenylene group or a naphthylene group substituted with at least one of a phenyl group, a naphthyl group, an anthracenyl group, or a fluorenyl group; or v) a phenylene group or a naphthylene group substituted with at least one of a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a tert-butyl group, a pyrrolyl group, an imidazolyl group, a triazolyl group, an isoindolyl group, an indolyl group, an indazolyl group, a purinyl group, a benzoimidazolyl group, an oxazolyl group, an isoxazolyl group, an oxadiazolyl group, or a benzoxazolyl group, but X_1 to X_4 are not limited thereto.

For example, X_1 to X_4 in Formulas 1 and 2 may each independently be at least one group represented by one of Formulas 4a to 4d below, but are not limited thereto:

<Formula 4a>



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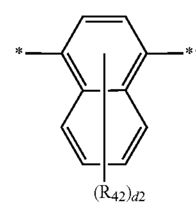

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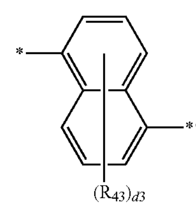

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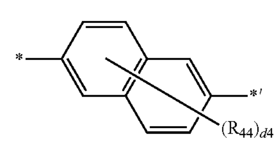


In Formulas 4a to 4d, R_{41} to R_{44} may each independently be a deuterium atom, —F, a cyano group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group.

d1 is an integer of 0 to 4. If d1 is an integer of 2 or more, the 2 or more R_{41} groups are the same or different.

d2 to d4 are each independently an integer of 0 to 6. If d2 is an integer of 2 or more, the 2 or more R_{42} group are the same or different, if d3 is a integer of 2 or more, the 2 or more R_{43} groups are the same or different, and if d4 is a integer of 2 or more, the 2 or more R_{44} groups are the same or different.

* is a bonding site to a pyrene ring, and *' is a bonding site to N, Z_1 or Z_2.

According to an embodiment of the present invention, in Formulas 1 and 2, n1, n2, n3 and n4 represent the numbers of X_1 groups, X_2 groups, X_3 groups and X_4 groups, respectively. n1 to n4 are each independently an integer of 0 to 5. If n1 is an integer of 2 or more, the 2 or more X_1 groups may be the same or different, if n2 is an integer of 2 or more, the 2 or more X_2 groups may be the same or different, if n3 is an integer of 2 or more, the 2 or more X_3 groups may be the same or different, and if n4 is an integer of 2 or more, the 2 or more X_4 groups may be the same or different, but n1 to n4 are not limited thereto.

For example, in Formulas 1 and 2, n1 to n4 may each be 1, but n1 to n4 are not limited thereto.

According to an embodiment of the present invention, in Formula 1, Y_1 to Y_4 may each independently be a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_2-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{30} aryl group, or a substituted or unsubstituted C_2-C_{30} heteroaryl group.

For example, in Formula 1 above, Y_1 to Y_4 may each independently be a substituted or unsubstituted phenyl group, a substituted or unsubstituted pentalenyl group, a substituted or unsubstituted indenyl group, a substituted or unsubstituted naphthyl group, a substituted or unsubstituted azulenyl group, a substituted or unsubstituted heptalenyl group, a substituted or unsubstituted indacenyl group, a substituted or unsubstituted acenaphthyl group, a substituted or unsubstituted fluorenyl group, a substituted or unsubstituted phenalenyl group, a substituted or unsubstituted phenanthrenyl group, a substituted or unsubstituted anthryl group, a substituted or unsubstituted fluoranthenyl group, a substituted or unsubstituted triphenylenyl group, a substituted or unsubstituted pyrenyl group, a substituted or unsubstituted chrysenyl group, a substituted or unsubstituted naphthacenyl group, a substituted or unsubstituted picenyl group, a substituted or unsubstituted perylenyl group, a substituted or unsubstituted pentaphenyl group, a substituted or unsubstituted hexacenyl group, a substituted or unsubstituted pyrrolyl group, a substituted or unsubstituted imidazolyl group, a substituted or unsubstituted pyrazolyl group, a substituted or unsubstituted pyridinyl group, a substituted or unsubstituted pyrazinyl group, a substituted or unsubstituted pyrimidinyl group, a substituted or unsubstituted pyridazinyl group, a substituted or unsubstituted isoindolyl group, a substituted or unsubstituted indolyl group, a substituted or unsubstituted indolyl group, a substituted or unsubstituted indazolyl group, a substituted or unsubstituted purinyl group, a substituted or unsubstituted quinolinyl group, a substituted or unsubstituted benzoquinolinyl group, a substituted or unsubstituted phthalazinyl group, a substituted or unsubstituted naphthyridinyl group, a substituted or unsubstituted quinoxalinyl group, a substituted or unsubstituted quinazolinyl group, a substituted or unsubstituted cinnolinyl group, a substituted or unsubstituted carbazolyl group, a substituted or unsubstituted phenanthridinyl group, a substituted or unsubstituted acridinyl group, a substituted or unsubstituted phenanthrolinyl group, a substituted or unsubstituted phenazinyl group, a substituted or unsubstituted benzoimidazolyl group, a substituted or unsubstituted furanyl group, a substituted or unsubstituted benzofuranyl group, a substituted or unsubstituted thiophenyl group, a substituted or unsubstituted benzothiophenyl group, a substituted or unsubstituted thiazolyl group, a substituted or unsubstituted isothiazolyl group, a substituted or unsubstituted benzothiazolyl group, a substituted or unsubstituted isoxazolyl group, a substituted or unsubstituted oxazolyl group, a substituted or unsubstituted triazolyl group, a substituted or unsubstituted tetrazolyl group, a substituted or unsubstituted oxadiazolyl group, a substituted or unsubstituted triazinyl group, a substituted or unsubstituted benzoxazolyl group, a substituted or unsubstituted dibenzopuranyl group, a substituted or unsubstituted dibenzothiophenyl group, or a substituted or unsubstituted benzocarbazolyl group, but Y_1 to Y_4 are not limited thereto.

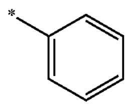
For example, in Formula 1, Y_1 to Y_4 may each independently be i) a phenyl group, a naphthyl group, an anthracenyl group, or a fluorenyl group; or ii) a phenyl group, a naphthyl group, an anthryl group, or a fluorenyl group substituted with at least one of a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, or a C_1-C_{10} alkyl group; a C_1-C_{10} alkyl group substituted with at least one of a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, or a C_6-C_{16} aryl group or a C_2-C_{16} heteroaryl group; or a C_6-C_{16} aryl group or a C_2-C_{16} heteroaryl group substituted with at least one of a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid or a salt thereof, a phosphoric acid or a salt thereof, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_6-C_{16} aryl group, or a C_6-C_{16} aryl group, and a C_2-C_{16} heteroaryl group, but Y_1 to Y_4 are not limited thereto.

For example, in Formula 1, Y_1 to Y_4 may each independently be selected from i) a phenyl group, a naphthyl group, or a fluorenyl group; ii) a phenyl group, a naphthyl group, or a fluorenyl group substituted with a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group; iii) a phenyl group, a naphthyl group, an anthracenyl group, or a fluorenyl group substituted with at least one of a phenyl group, a naphthyl group, an anthracenyl group, or a fluorenyl group; or iv) a phenyl group, a naphthyl group, or a fluorenyl group substituted with at least one of a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a tert-butyl group, a phenyl group, a naphthyl group, an anthracenyl group, or a fluorenyl group, but Y_1 to Y_4 are not limited thereto.

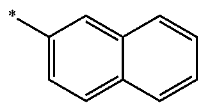
For example, in Formula 1, Y_1 to Y_4 may each independently be selected from i) a phenyl group, a naphthyl group, or a fluorenyl group; ii) a phenyl group, a naphthyl group, or a fluorenyl group substituted with at least one of a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group; or iii) a phenyl group, a naphthyl group, or a fluorenyl group substituted with at least one of a phenyl group, a naphthyl group, an anthracenyl group, or a fluorenyl group, but Y_1 to Y_4 are not limited thereto.

For example, in Formula 1, Y_1 to Y_4 may each independently be at least one group represented by one of Formulas 5a to 5f, but Y_1 to Y_4 are not limited thereto:

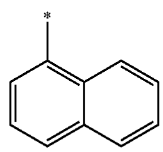
<Formula 5a>



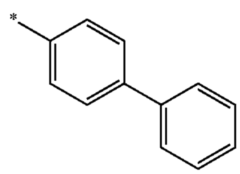
<Formula 5b>



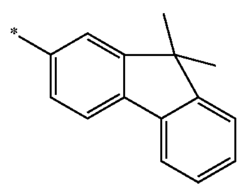
<Formula 5c>



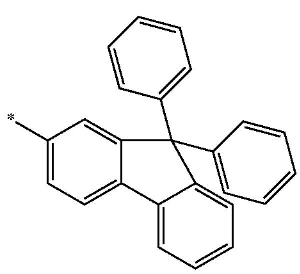
<Formula 5d>



<Formula 5e>



<Formula 5f>



In Formulas 5a to 5f, * is a bonding site to N, Z_1 or Z_2.

According to an embodiment of the present invention, in Formulas 1 and 2, Z_1 and Z_2 may each independently be a substituted or unsubstituted C_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkenyl group, or a substituted or unsubstituted C_2-C_{60} heteroaryl group, but Z_1 and Z_2 are not limited thereto.

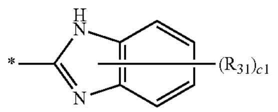
For example, in Formula 2, Z_1 and Z_2 may independently be a substituted or unsubstituted pyrrolyl group, a substituted or unsubstituted imidazolyl group, a substituted or unsubstituted pyrazolyl group, a substituted or unsubstituted triazolyl group, a substituted or unsubstituted pyridinyl group, a substituted or unsubstituted pyrazinyl group, a substituted or unsubstituted pyrimidinyl group, a substituted or unsubstituted pyridazinyl group, a substituted or unsubstituted triazinyl group, a substituted or unsubstituted isoindolyl group, a substituted or unsubstituted indolyl group, a substituted or unsubstituted indazolyl group, a substituted or unsubstituted purinyl group, a substituted or unsubstituted quinolinyl group, a substituted or unsubstituted benzoquinolinyl group, a substituted or unsubstituted phthalazinyl group, a substituted or unsubstituted naphthyridinyl group, a substituted or unsubstituted quinoxalinyl group, a substituted or unsubstituted quinazolinyl group, a substituted or unsubstituted cinnolinyl group, a substituted or unsubstituted carbazolyl group, a substituted or unsubstituted phenanthridinyl group, a substituted or unsubstituted acridinyl group, a substituted or unsubstituted phenanthrolinyl group, a substituted or unsubstituted phenazinyl group, a substituted or unsubstituted benzoimidazolyl group, a substituted or unsubstituted oxazolyl group, a substituted or unsubstituted isoxazolyl group, a substituted or unsubstituted oxadiazolyl group, a substituted or unsubstituted benzoxazolyl group, or a substituted or unsubstituted benzocarbazolyl group, but Z_1 and Z_2 are not limited thereto.

For example, in Formula 2, Z_1 and Z_2 may each independently be i) a pyrrolyl group, an imidazolyl group, a triazolyl group, a pyridyl group, a triazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a benzoimidazolyl group, an oxazolyl group, an isoxazolyl group, an oxadiazolyl group, or a benzoxazolyl group; or ii) a pyrrolyl group, an imidazolyl group, a triazolyl group, a pyridyl group, a triazinyl group, an isoindolyl group, an indolyl group, an indazolyl group, a benzoimidazolyl group, an oxazolyl group, an isoxazolyl group, an oxadiazolyl group, or a benzoxazolyl group substituted with at least one of a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, or a C_1-C_{10} alkyl group; a C_6-C_{16} aryl group or a C_2-C_{16} heteroaryl group; or a C_6-C_{16} aryl group or a C_2-C_{16} heteroaryl group substituted with at least one of a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a C_6-C_{16} aryl group, or a C_2-C_{16} heteroaryl group, but Z_1 and Z_2 are not limited thereto.

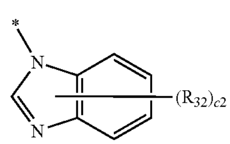
For example, in Formula 2, Z_1 and Z_2 may each independently be i) a triazolyl group, a pyridyl group, a triazinyl group, a benzoimidazolyl group, or an oxadiazolyl group; ii) a triazolyl group, a pyridyl group, a triazinyl group, a benzoimidazolyl group, or an oxadiazolyl group substituted with at least one of a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group; iii) a triazolyl group, a pyridyl group, a triazinyl group, a benzoimidazolyl group, or an oxadiazolyl group substituted with at least one of a phenyl group, a naphthyl group, an anthracenyl group, a pyrrolyl group, an imidazolyl group, a pyrazolyl group, or a triazolyl group; or iv) a triazolyl group, a pyridyl group, a triazinyl group, a benzoimidazolyl group, or an oxadiazolyl group substituted with at least one of a phenyl group, a naphthyl group, an anthracenyl group, a pyrrolyl group, an imidazolyl group, a pyrazolyl group, or a triazolyl group substituted with at least one of a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, a tert-butyl group, a phenyl group, a naphthyl group, or an anthracenyl group, but Z_1 and Z_2 are not limited thereto.

For example, in Formula 2, Z_1 and Z_2 may each independently be a group represented by one of Formulas 3a to 3i, but Z_1 and Z_2 are not limited thereto:

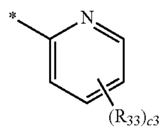
<Formula 3a>



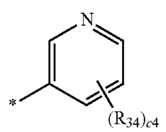
<Formula 3b>



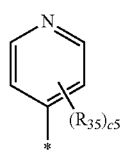
<Formula 3c>



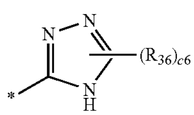
<Formula 3d>



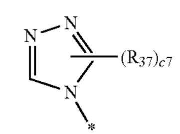
<Formula 3e>



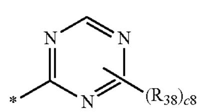
<Formula 3f>



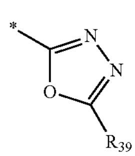
<Formula 3g>



<Formula 3h>



<Formula 3i>



In Formulas 3a to 3i, R_{31} to R_{39} may each independently be a hydrogen atom, a deuterium atom, —F, a cyano group, a methyl group, an ethyl group, a phenyl group, a biphenyl group, or a naphthyl group.

c1 to c8 may each independently be an integer of 0 to 4. If c1 is an integer of 2 or more, the 2 or more R_{31} groups may be the same or different, if c2 is an integer of 2 or more, the 2 or more R_{32} groups may be the same or different, if c3 is an integer of 2 or more, the 2 or more R_{33} groups may be the same or different, if c4 is an integer of 2 or more, the 2 or more R_{34} groups may be the same or different, if c5 is an integer of 2 or more, the 2 or more R_{35} groups may be the same or different, if c6 is an integer of 2 or more, the 2 or more R_{35} groups may be the same or different, if c6 is an integer of 2 or more, the 2 or more R_{36} groups may be the same or different, if c7 is an integer of 2 or more, the 2 or more R_{37} groups may be the same or different, and if c8 is an integer of 2 or more, the 2 or more R_{38} groups may be the same or different.

* is a bonding site to X_3 or X_4.

According to an embodiment of the present inventive concept, in Formulas 1 and 2, R_1 to R_4 may each independently be selected from a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic add group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a phosphoric acid group or a salt thereof, a substituted or unsubstituted C_1-C_{60} alkyl group, a substituted or unsubstituted C_2-C_{60} alkenyl group, a substituted or unsubstituted C_2-C_{60} alkynyl group, a substituted or unsubstituted C_1-C_{60} alkoxy group, a substituted or unsubstituted C_3-C_{10} cycloalkyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkyl group, a substituted or unsubstituted C_3-C_{10} cycloalkenyl group, a substituted or unsubstituted C_2-C_{10} heterocycloalkenyl group, a substituted or unsubstituted C_6-C_{60} aryl group, a substituted or unsubstituted C_6-C_{60} aryloxy group, a substituted or unsubstituted C_6-C_{60} arylthio group, or a substituted or unsubstituted C_2-C_{60} heteroaryl group, but R_1 to R_4 are not limited thereto.

For example, in Formulas 1 and 2, R_1 to R_4 may each independently be a hydrogen atom, a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, and a C_1-C_{10} alkyl group; or a C_1-C_{10} alkyl group substituted with at least one of a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a phosphoric acid group or a salt thereof; a C_6-C_{16} aryl group; or a C_6-C_{16} aryl group substituted with at least one of a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{10} alkyl group, a C_1-C_{10} alkoxy group, a phenyl group, a naphthyl group, or an anthryl group, but R_1 to R_4 are not limited thereto.

For example, in Formulas 1 and 2, R_1 to R_4 may each independently be a hydrogen atom, a deuterium atom, an —F, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group; a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group substituted with at least one of a hydrogen atom, a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group; or a phenyl group, a naphthyl group, or an anthracenyl group substituted with at least one of a hydrogen atom, a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group, but R_1 to R_4 are not limited thereto.

For example, in Formulas 1 and 2, R_1 to R_4 may be the same, but are not limited thereto. In one embodiment, for example, R_1 to R_4 may all be hydrogen atoms.

According to an embodiment of the present inventive concept, in Formulas 1 and 2, a1 to a4 each independently represent numbers each of R_1 to R_4, a1 to a4 are each independently an integer of 0 to 4, and if a1 is an integer of 2 or more, then 2 or more of R_1 may be the same or different, if a2 is an integer of 2 or more, then 2 or more of R_2 may be the same or different, if a3 is a an integer of 2 or more, then 2 or more of R_3 may be the same or different, and if a4 is an integer of 2 or more, then 2 or more of R_4 may be the same or different, but not limited thereto.

For example, in Formula 1, a1 may be 0, but is not limited thereto.

For example, in Formula 1, a2 may be 0, but is not limited thereto.

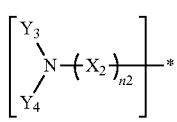
For example, in Formula 1, a1 may be 0 and a2 may be 0, but a1 and a2 are not limited thereto. Here, if a1 and a2 are both 0, the pyrene ring is not substituted.

For example, in Formula 2, a3 may be 0, but is not limited thereto.

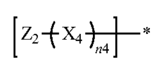
For example, in Formula 2, a4 may be 0, but is not limited thereto.

For example, in Formula 2, a3 may be 0 and a4 may be 0, but a3 and a4 are not limited thereto. Here, if a3 and a4 are both 0, the pyrene ring is not substituted.

According to an embodiment of the present invention, in Formulas 1 and 2, b1 represents the number of moieties represented by



(where * is a linking site to a pyrene ring), and b2 represents the number of moieties represented by

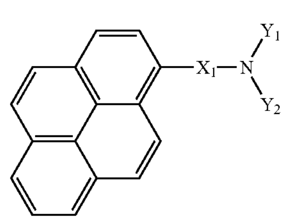


(where * is a linking site to a pyrene ring). b1 and b2 may each independently be an integer 0 or 1, but b1 and b2 are not limited thereto.

For example, in Formulas 1 and 2, b1 and b2 may each independently be 0, but b1 and b2 are not limited thereto.

According to an embodiment of the present invention, the amine-based compound may be represented by Formula 1a below, but is not limited thereto.

<Formula 1a>

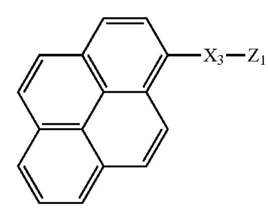


In Formula 1a, X_1 may be a phenylene group or a naphthylene group; or a phenylene group or a naphthylene group substituted with at least one of a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group.

Y_1 and Y_2 may each independently be i) a phenyl group, a naphthyl group, or a fluorenyl group; ii) a phenyl group, a naphthyl group, or a fluorenyl group substituted with at least one of a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group; or iii) a phenyl group, a naphthyl group, or a fluorenyl group substituted with at least one of a phenyl group, a naphthyl group, an anthracenyl group, or a fluorenyl group.

According to an embodiment of the present invention, the pyrene-based compound may be represented by Formula 2a below, but is not limited thereto.

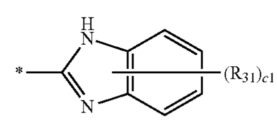
<Formula 2a>



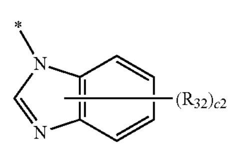
In Formula 2a, X_3 may be a phenylene group or a naphthylene group; or a phenylene group or a naphthylene group substituted with at least one of a deuterium atom ion, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group.

Z_1 and Z_2 may be each independently at least one group represented by one of Formulas 3a to 3i below, but Z_1 and Z_2 are not limited thereto:

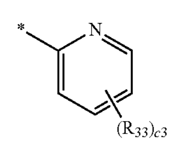
<Formula 3a>



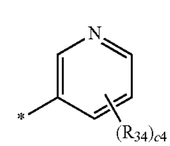
<Formula 3b>



<Formula 3c>



<Formula 3d>



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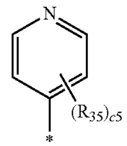
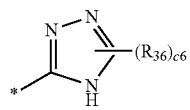
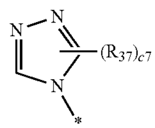
<Formula 3e>



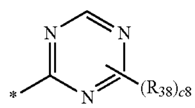
<Formula 3f>



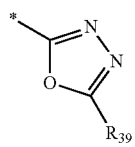
<Formula 3g>



<Formula 3h>



<Formula 3i>



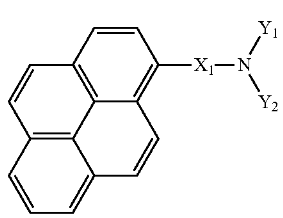
In Formulas 3a to 3i, R_{31} to R_{39} may each independently be a hydrogen atom, a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, a phenyl group, a biphenyl group, or a naphthyl group.

c1 to c5 may each independently an integer of 0 to 4. If c1 is an integer of 2 or more, the 2 or more R_{31} groups may be the same or different, if c2 is an integer of 2 or more, the 2 or more R_{32} groups may be the same or different, if c3 is an integer of 2 or more, the 2 or more R_{33} groups may be the same or different, if c4 is an integer of 2 or more, the 2 or more R_{34} groups may be the same or different, if c5 is an integer of 2 or more, the 2 or more R_{35} groups may be the same or different, if c6 is an integer of 2 or more, the 2 or more R_{36} groups may be the same or different, if c7 is an integer of 2 or more, the 2 or more R_{37} groups may be the same or different, and if c8 is an integer of 2 or more, the 2 or more R_{38} groups may be the same or different.

* is a bonding site to X_3 or X_4.

According to an embodiment of the present invention, the amine-based compound may be represented by Formula 1a below, and the pyrene-based compound may be represented by Formula 2a below, but the amine-based compound and pyrene-based compound are not limited thereto:

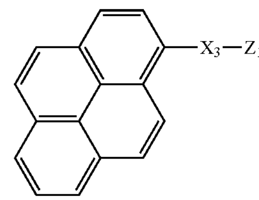
<Formula 1a>



In Formula 1a, X_1 may be a phenylene group or a naphthylene group; or a phenylene group or a naphthylene group substituted with at least one of a deuterium atom ion, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group.

Y_1 and Y_2 may each independently be at least one of i) a phenyl group, a naphthyl group, or a fluorenyl group; ii) a phenyl group, a naphthyl group, or a fluorenyl group substituted with at least one of a deuterium atom ion, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group; or iii) a phenyl group, a naphthyl group, or a fluorenyl group substituted with at least one of a phenyl group, a naphthyl group, an anthracenyl group, or a fluorenyl group.

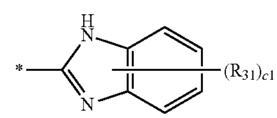
<Formula 2a>



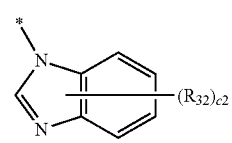
In Formula 2a, X_3 may be a phenylene group or a naphthylene group; or a phenylene group or a naphthylene group substituted with at least one of a deuterium atom ion, —F, a cyano group, a nitro group, a methyl group, an ethyl group, an n-propyl group, an iso-propyl group, an n-butyl group, an iso-butyl group, or a tert-butyl group.

Z_1 may be at least one group represented by one of Formulas 3a to 3i below, but Z_1 is not limited thereto.

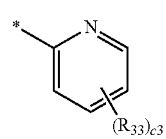
<Formula 3a>



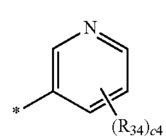
<Formula 3b>



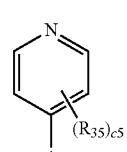
<Formula 3c>



<Formula 3d>



<Formula 3e>



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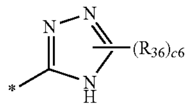
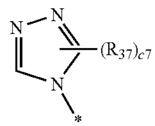
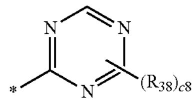
<Formula 3f>



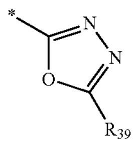
<Formula 3g>



<Formula 3h>



<Formula 3i>



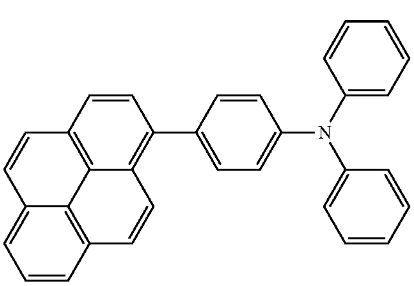
In Formulas 3a to 3i, R_{31} to R_{39} may each independently be a hydrogen atom, a deuterium atom, —F, a cyano group, a nitro group, a methyl group, an ethyl group, a phenyl group, a biphenyl group, or a naphthyl group.

c1 to c8 may each independently be an integer of 0 to 4. If c1 is an integer of 2 or more, the 2 or more R_{31} groups may be the same or different, if c2 is an integer of 2 or more, the 2 or more R_{32} groups may be the same or different, if c3 is an integer of 2 or more, the 2 or more R_{33} groups may be the same or different, if c4 is an integer of 2 or more, the 2 or more R_{34} groups may be the same or different, if c5 is an integer of 2 or more, the 2 or more R_{35} groups may be the same or different, if c6 is an integer of 2 or more, the 2 or more R_{36} groups may be the same or different, if c7 is an integer of 2 or more, the 2 or more R_{37} groups may be the same or different, and if c8 is an integer of 2 or more, the 2 or more R_{35} groups may be the same or different.

* may be a bonding site to X_3 or X_4, but not limited thereto.

According to embodiments of the present invention, the amine-based compound may be at least one of Compounds 1 to 14 below, but the amine-based compound is not limited thereto.

<Compound 1>



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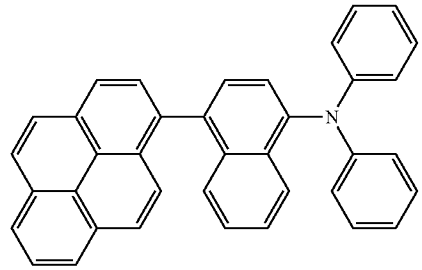
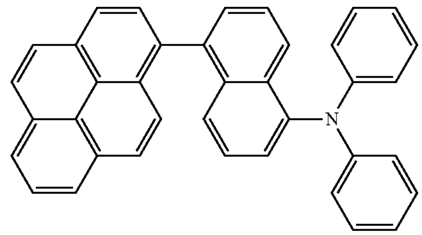
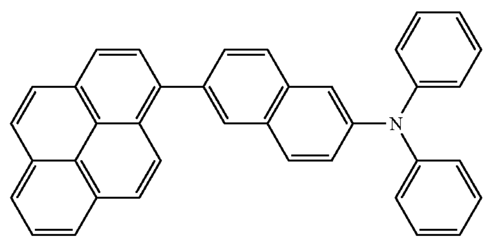
<Compound 2>



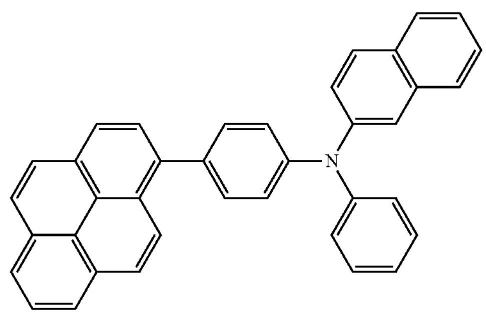
<Compound 3>



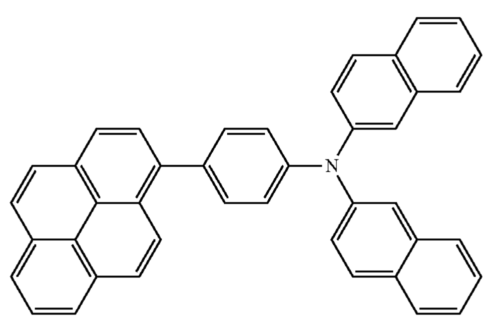
<Compound 4>



<Compound 5>



<Compound 6>



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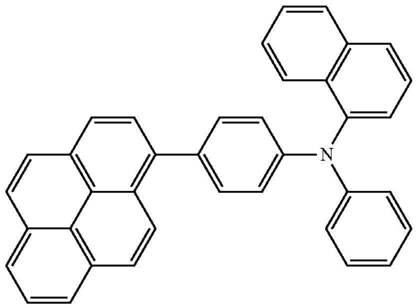
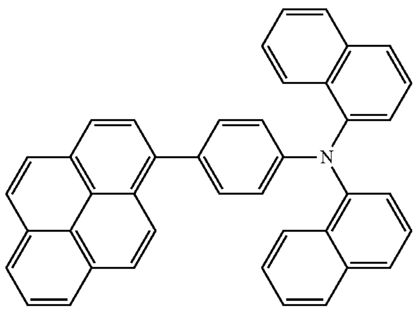
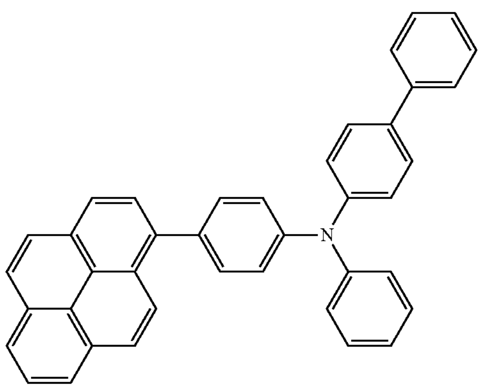
<Compound 7>



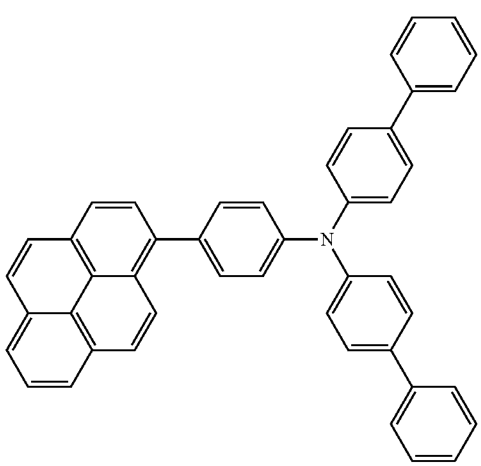
<Compound 8>



<Compound 9>



<Compound 10>



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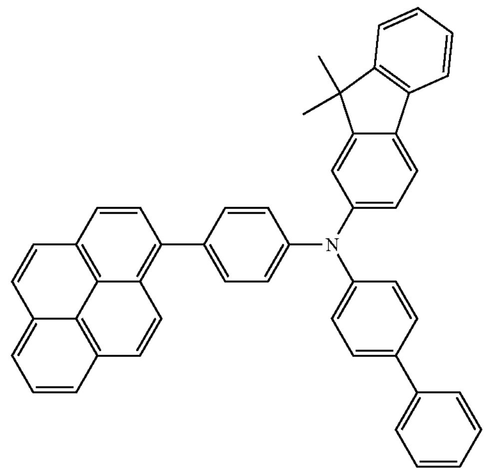
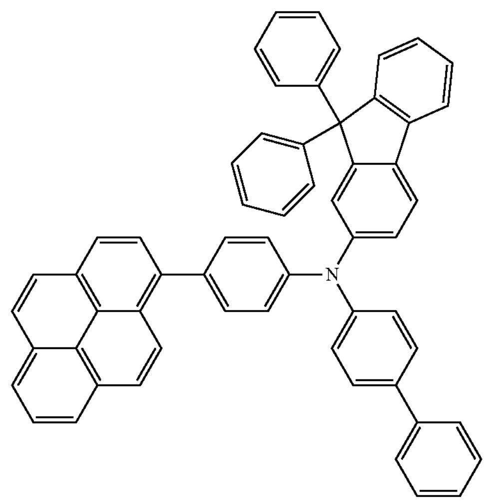
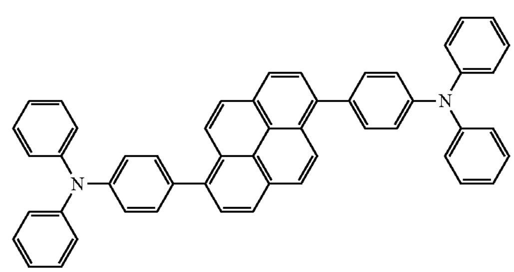
<Compound 11>



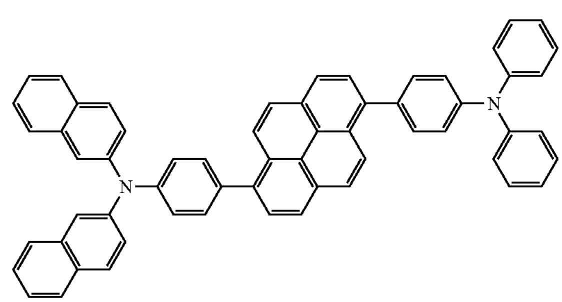
<Compound 12>



<Compound 13>

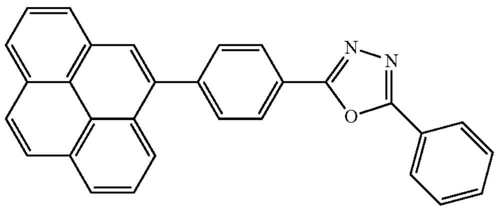


<Compound 14>

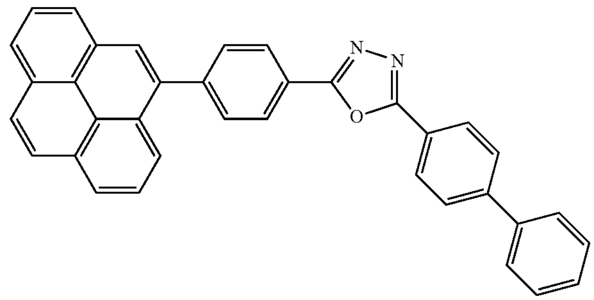


According to embodiments of the present invention, the pyrene-based compound may be at least one of Compounds 15 to 21 below, but the pyrene-based compound is not limited thereto:

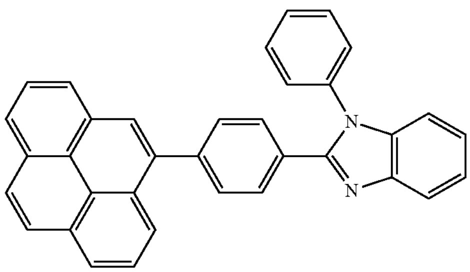
<Compound 15>



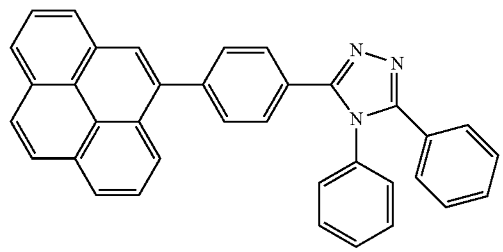
<Compound 16>



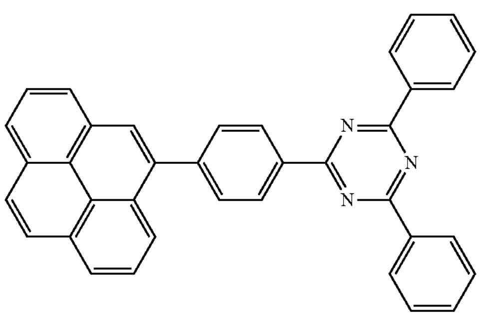
<Compound 17>



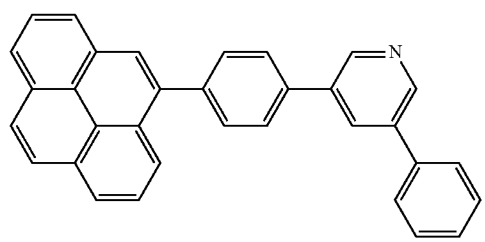
<Compound 18>



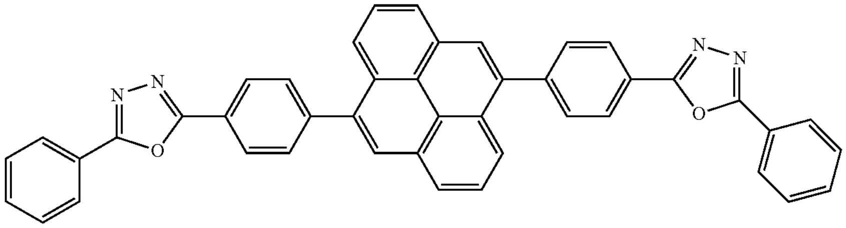
<Compound 19>



<Compound 20>

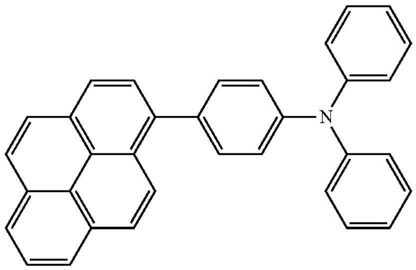


<Compound 21>

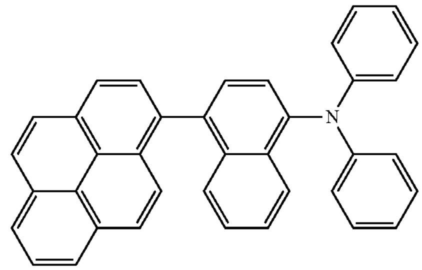


According to embodiments of the present invention, the amine-based compound may be one of Compounds 1 to 14 below, and the pyrene-based compound may be one of Compounds 15 to 21, but the amine-based compound and the pyrene-based compound are not limited thereto.

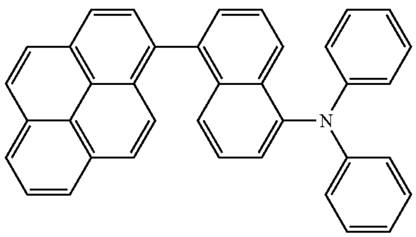
<Compound 1>



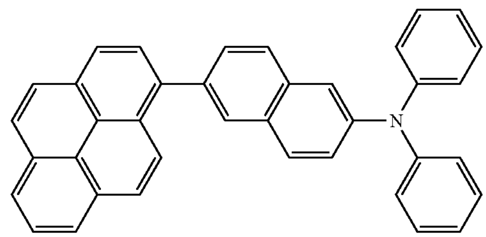
<Compound 2>



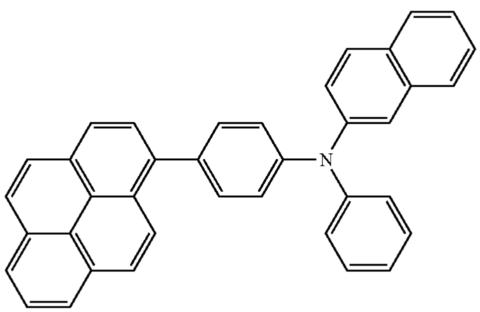
<Compound 3>



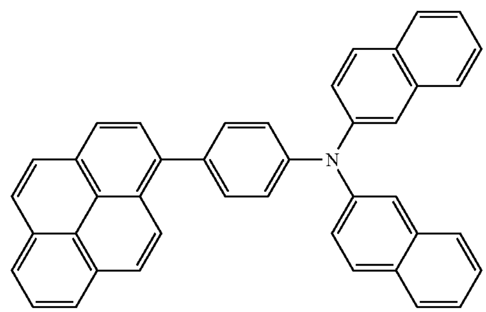
<Compound 4>



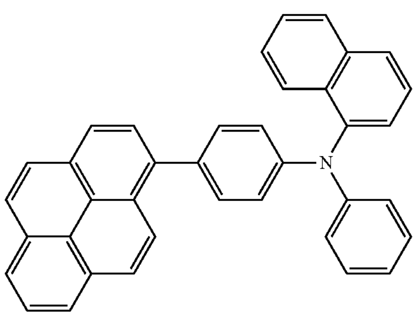
<Compound 5>



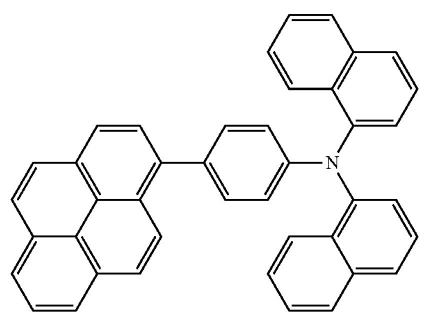
<Compound 6>



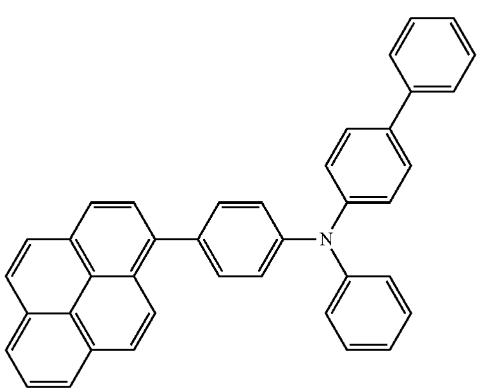
<Compound 7>



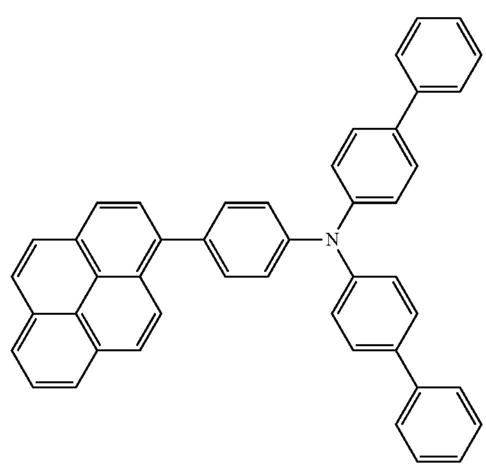
<Compound 8>



<Compound 9>



<Compound 10>



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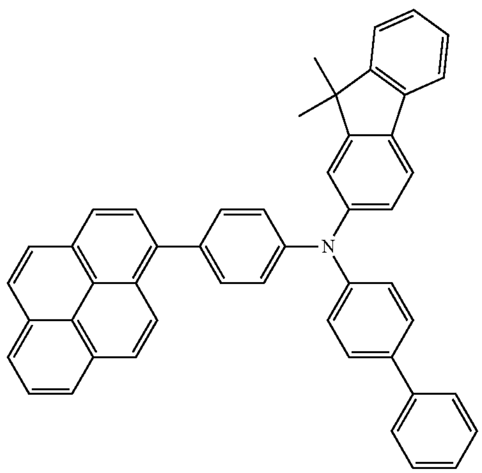
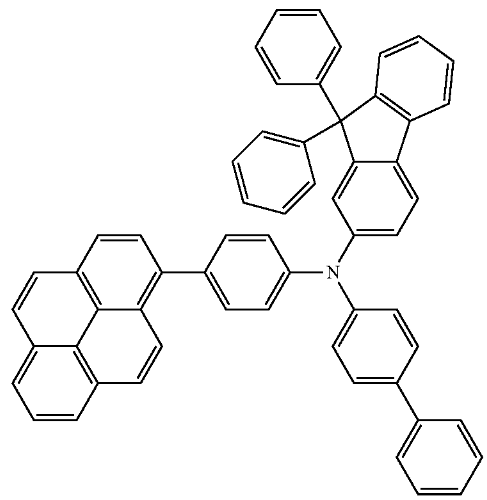
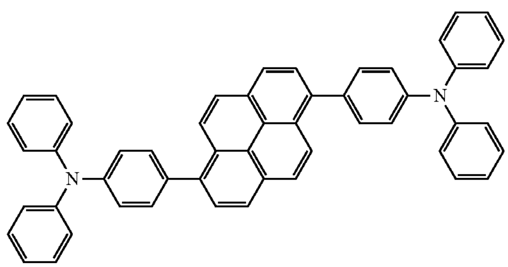
<Compound 11>



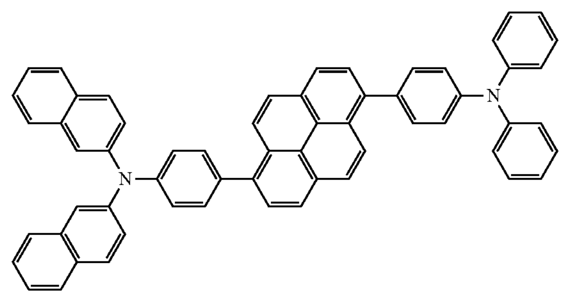
<Compound 12>



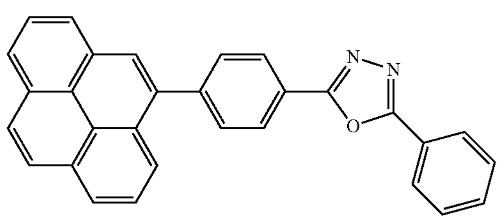
<Compound 13>



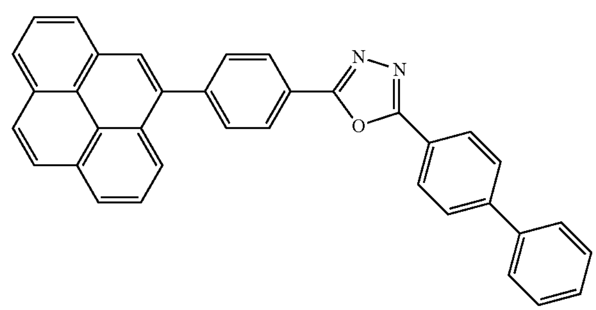
<Compound 14>



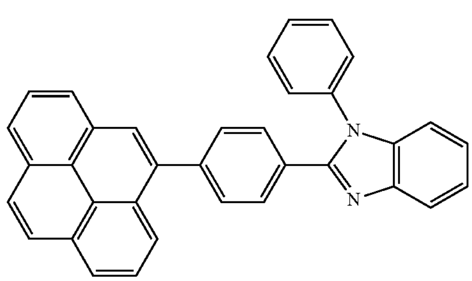
<Compound 15>



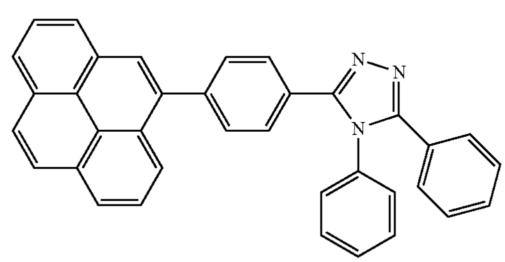
<Compound 16>



<Compound 17>



<Compound 18>



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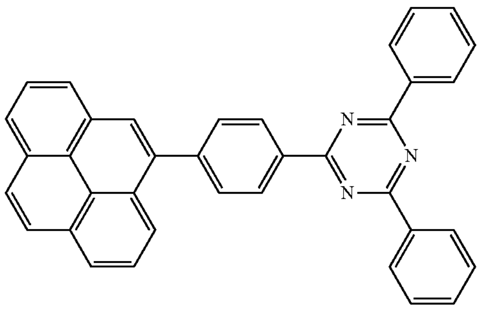
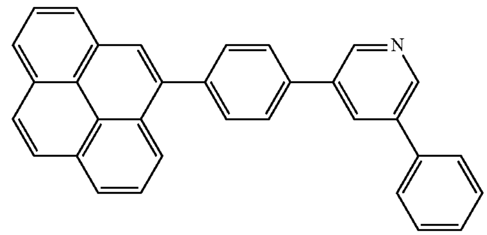
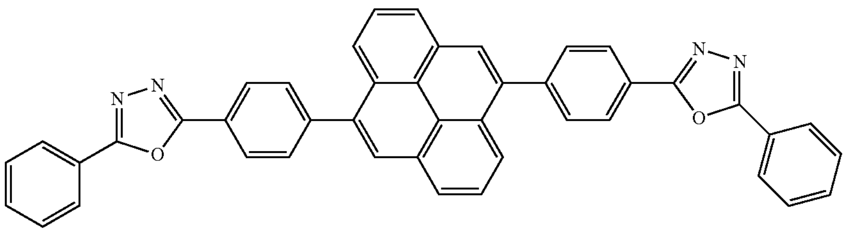
<Compound 19>



<Compound 20>



<Compound 21>



The amine-based compound represented by Formula 1 is a material having good hole transport ability. Also, the pyrene-based compound represented by Formula 2 is a material having good electron transport ability. Accordingly, by using both an amine-based compound having good hole transport ability and a pyrene-based compound having good electron transport ability in an organic layer, holes and electrons are sufficiently supplied in the organic layer, thus improving efficiency. Also, the emission layer has both hole affinity and electron affinity, thereby substantially preventing sharp reductions in lifespan caused by a predominance of one of the carriers in the emission layer.

The organic layer includes a hole transport region between the first electrode and the emission layer, and has at least one of a hole injection layer, a hole transport layer, a functional layer having both hole injection ability and hole transport ability (hereinafter referred to as an 'H-functional layer'), a buffer layer, and/or an electron blocking layer. The organic layer also has an electron transport region between the emission layer and the second electrode, and has at least one of a hole blocking layer, an electron transport layer, and/or an electron injection layer.

According to an embodiment of the present invention, the amine-based compound and the pyrene-based compound may be included in the emission layer, but the present invention is not limited thereto.

For example, the amine-based compound and the pyrene-based compound may be co-deposited, but the present invention is not limited thereto.

For example, the amine-based compound and the pyrene-based compound may be co-deposited in a weight ratio of about 3:1 to about 1:3, but the present invention is not limited thereto. When the ratio of co-deposition is within this range, the organic light-emitting diode may have higher efficiency.

For example, the emission layer may include a first emission layer and a second emission layer, and the first emission layer may include the amine-based compound, and the second emission layer may include the pyrene-based compound, but the present invention is not limited thereto.

For example, the first emission layer may be disposed between the second emission layer and the first electrode, but the present invention is not limited thereto.

FIG. **1** is a schematic view of an organic light-emitting diode **10** according to an embodiment of the present invention. Hereinafter, a structure and a method of manufacturing the organic light-emitting diode, according to an embodiment of the present invention, will be described with reference to FIG. **1**.

A substrate **11** may be any substrate conventionally used in organic light-emitting devices. In some embodiments, the substrate **11** may be a glass substrate or a transparent plastic substrate with good mechanical strength, thermal stability, transparency, surface smoothness, ease of handling, and water resistance.

A first electrode **13** may be formed by depositing or sputtering a first electrode-forming material onto a surface of the substrate **11**. When the first electrode **13** is an anode, a material having a high work function may be used as the first electrode-forming material to facilitate hole injection. The first electrode **13** may be a reflective electrode or a transmission electrode. Transparent and conductive materials such as ITO, IZO, SnO_2, and ZnO may be used to form the first electrode **13**. The first electrode **13** may be formed as a reflective electrode using magnesium (Mg), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), or the like.

The first electrode **13** may have a single-layer structure or a multi-layer structure including at least two layers. For example, the first electrode **13** may have a three-layered structure of ITO/Ag/ITO, but is not limited thereto.

An organic layer **15** may be disposed on the first electrode **13**.

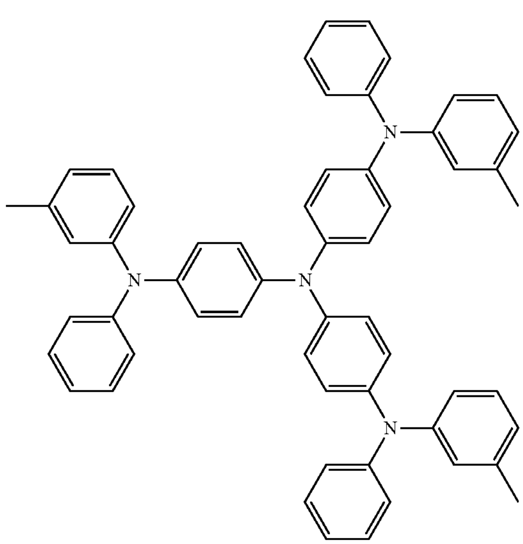
The organic layer **15** may include a hole injection layer (HIL), a hole transport layer (HTL), a buffer layer, an emission layer (EML), an electron transport layer (ETL), and an electron injection layer (EIL).

The HIL may be formed on the first electrode **13** by vacuum deposition, spin coating, casting, Langmuir-Blodgett (LB) deposition, or the like. When the HIL is formed using vacuum deposition, the vacuum deposition conditions may vary depending on the compound used to form the HIL, and the desired structure and thermal properties of the HIL to be formed. For example, vacuum deposition may be performed at a temperature of about 100° C. to about 500° C., a pressure of about 10^{-8} torr to about 10^{-3} torr, and a deposition rate of about 0.01 Å/sec to about 100 Å/sec. However, the deposition conditions are not limited thereto.

When the HIL is formed using spin coating, the coating conditions may vary according to the compound that is used to form the HIL, and the desired structure and thermal properties of the HIL to be formed. For example, the coating rate may be in a range of about 2000 rpm to about 5000 rpm, and a temperature at which heat treatment is performed to remove solvent after coating may be in a range of about 80° C. to about 200° C. However, the coating conditions are not limited thereto.

The HIL may be formed of any material that is commonly used to form an HIL. Non-limiting examples of the material that may be used to form the HIL are N,N'-diphenyl-N,N'-bis-[4-(phenyl-m-tolyl-amino)-phenyl]-biphenyl-4,4'-diamine, (DNTPD), a phthalocyanine compound such as copper phthalocyanine, 4,4',4"-tris (3-methylphenylphenylamino)triphenylamine (m-MTDATA), N,N'-di(1-naphthyl-N,N'-diphenylbenzidine (NPB), TDATA, 2T-NATA, polyaniline/dodecylbenzenesulfonic acid (Pani/DBSA), poly(3,4-ethylenedioxythiophene)/poly(4-styrenesulfonate) (PEDOT/PSS), polyaniline/camphor sulfonic acid (Pani/CSA), and polyaniline)/poly(4-styrenesulfonate (PANI/PSS), but not limited thereto.

m-MTDATA



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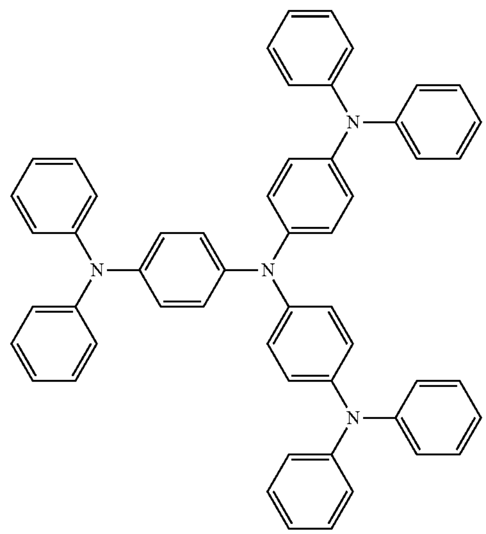
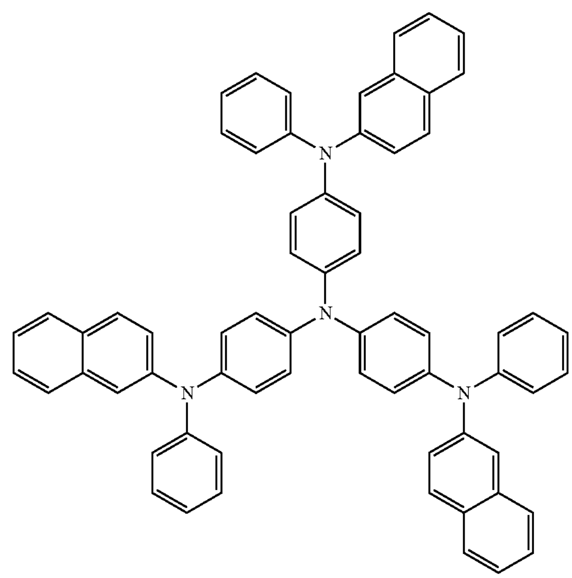
TDATA



2-TNATA

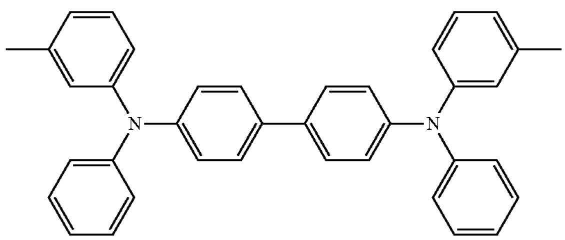


Alternatively, the HIL may include at least one type of silicon-based compound.

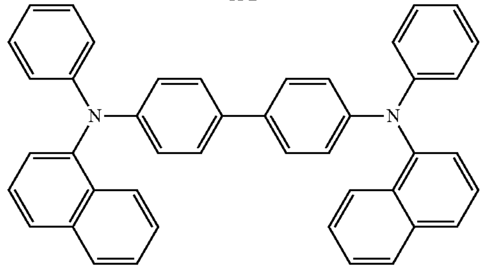
The thickness of the HIL may be about 100 Å to about 10000 Å, and in some embodiments, may be from about 100 Å to about 1000 Å. When the thickness of the HIL is within these ranges, the HIL may have good hole injecting ability without a substantial increase in driving voltage.

Then, an HTL may be formed on the HIL by vacuum deposition, spin coating, casting, LB deposition, or the like. When the HTL is formed using vacuum deposition or spin coating, the conditions for deposition or coating may be similar to those for the formation of the HIL, though the conditions for the deposition or coating may vary depending on the compound used to form the HTL.

Non-limiting examples of suitable known HTL forming materials include carbazole derivatives, such as N-phenyl-carbazole or polyvinylcarbazole, N,N'-bis(3-methylphenyl-N,N'-diphenyl-[1,1-biphenyl]-4,4'-diamine (TPD), 4,4',4"-tris(N-carbazolyl triphenylamine (TCTA), and N,N'-di(1-naphthyl-N,N'-diphenylbenzidine) (NPB). Alternatively, the HTL may include at least one type of silicon-based compound.



TPD



NPB

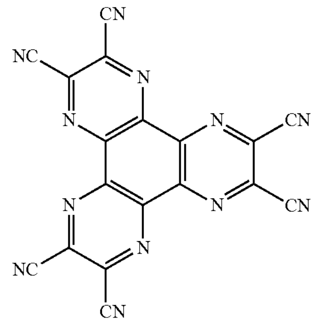
The thickness of the HTL may be from about 50 Å to about 2000 Å, and in some embodiments, may be from about 100 Å to about 1500 Å. When the thickness of the HTL is within these ranges, the HTL may have good hole transporting ability without a substantial increase in driving voltage.

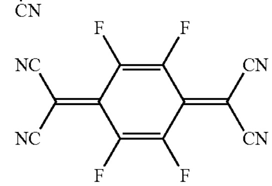
The H-functional layer (having both hole injection and hole transport capabilities) may include at least one hole injecting material and at least one hole transporting material. A thickness of the H-functional layer may be in a range of about 500 Å to about 10,000 Å, for example, about 100 Å to about 1,000 Å. When the thickness of the H-functional layer is within the above ranges, the H-functional layer may have good hole injection and transport capabilities without a substantial increase in driving voltage.

In some embodiments, in addition to the known hole injecting material, the known hole transporting material, and/or the material simultaneously having hole injection and transport capabilities described above, at least one of the HIL, HTL, and H-functional layer may further include an electric charge-generating material for improving conductivity of the layer.

Examples of the electric charge-generating material include quinine derivatives, metal oxides, and cyano compounds, but are not limited thereto. For example, non-limiting examples of the electric charge-generating compound include quinine derivatives such as tetracyanoquinodimethane (TCNQ) and 2,3,5,6-tetrafluoro-tetracyano-1,4-benzoquinodimethane (F4-TCNQ); metal oxides such as tungsten oxide and molybdenum oxide; and cyano compounds such as compound 200 below.

<compound 200>





<F4-TCNQ>

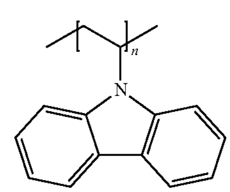
When the HIL, HTL, or H-functional layer further includes an electric charge-generating material, the electric charge-generating material may be included in any manner, such as being homogeneously dispersed or irregularly distributed in the HIL, HTL, or H-functional layer.

A buffer layer may be disposed between the EML and at least one of the HIL, HTL, and H-functional layer. The buffer layer may compensate for an optical resonance distance of light according to a wavelength of the light emitted from the EML, and thus may increase efficiency. The buffer layer may include any hole injecting material or hole transporting material. In some other embodiments, the buffer layer may include the same material as one of the materials included in the HIL, HTL, and H-functional layer that underlies the buffer layer.

Then, an EML may be formed on the HTL, H-functional layer, or buffer layer by vacuum deposition, spin coating, casting, LB deposition, or the like. When the EML is formed using vacuum deposition or spin coating, the deposition or coating conditions may be similar to those used to form the HIL, though the conditions for deposition and coating may vary depending on the compound used to form the EML.

The EML may include a known light-emitting material. For example, the EML may include a known host and a known dopant.

Nonlimiting examples of the host include Alq_3, CBP (4,4'-N,N'-dicarbazole-biphenyl), PVK (poly(n-vinylcarbazole)), 9,10-di(naphthylene-2-yl)anthracene (DNA), TCTA, TPBI (1,3,5-tris(N-phenylbenzimidazole-2-yl)benzene), TBADN (3-tert-butyl-9,10-di(naphth-2-yl) anthracene), mCP, OXD-7, or the like.



PVK

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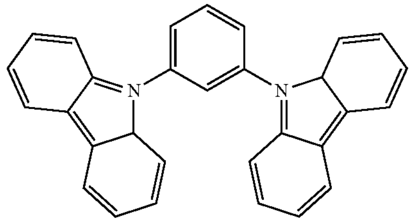
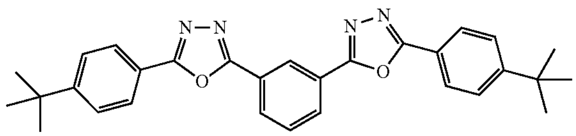


mCP

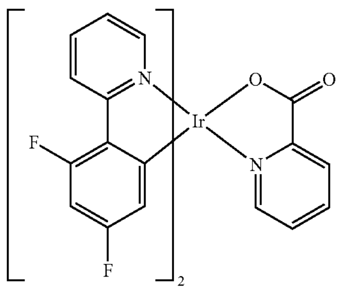


OXD-7

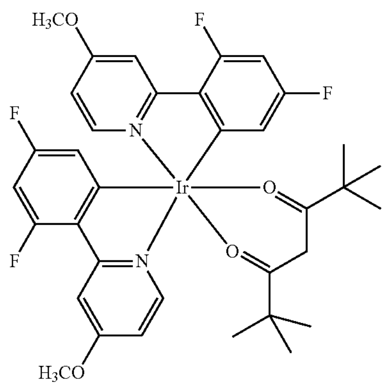
The dopant may be at least one or a fluorescent dopant or a phosphorescent dopant. The phosphorescent dopant may be an organic metal complex including a composite of at least two of Ir, Pt, Os, Re, Ti, Zr, Hf, or a combination thereof, but not limited thereto.

Examples of blue dopants include F_2Irpic, $(F_2ppy)_2$Ir (tmd), Ir(dfppz)$_3$, ter-fluorene, 4,4'-bis(4-diphenylaminostyryl)biphenyl (DPAVBi), 2,5,8,11-tetra-tert-butyl pherylene (TBPe), DPVBi, but are not limited thereto.

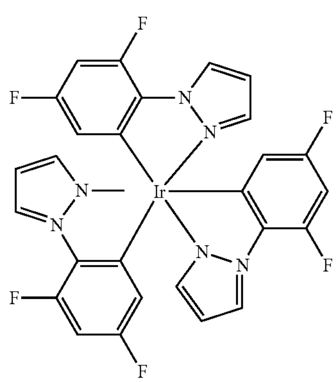
F_2Irpic



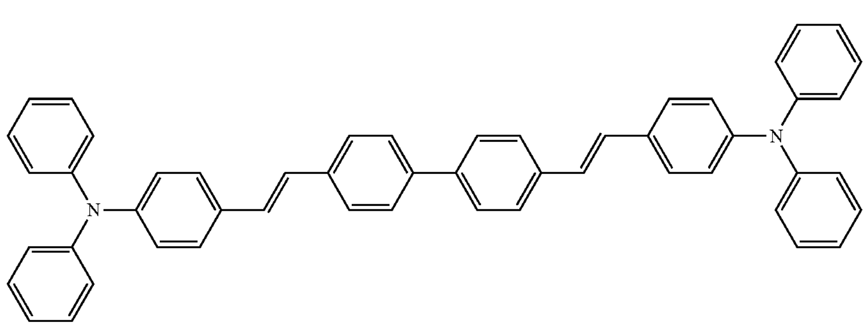
$(F_2ppy)_2$Ir(tmd)



Ir(dfppz)$_3$



DPAVBi



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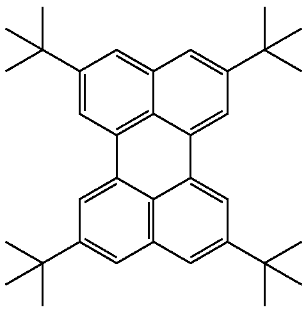
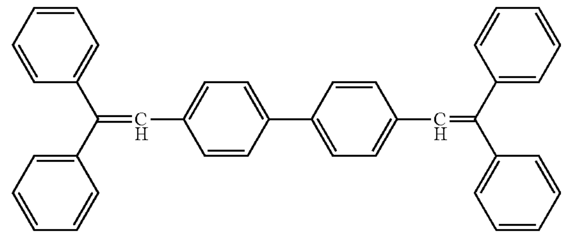
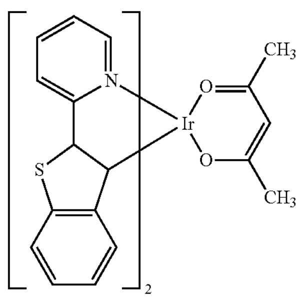
TBPe



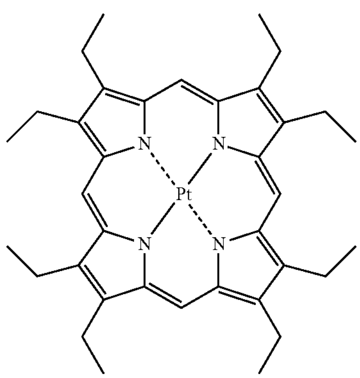
DPVBi



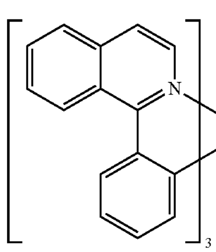
Examples of red dopants include PtOEP, Ir(piq)$_3$, Btplr, or the like, but are not limited thereto.



Btplr

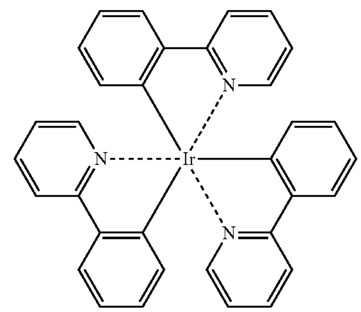


PtOEP

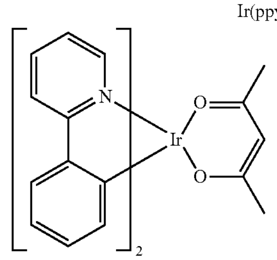


Ir(piq)$_3$

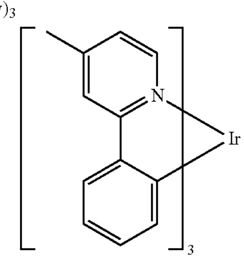
Examples of green dopants include Ir(ppy)$_3$ (ppy=phenylpyridine), Ir(ppy)$_2$(acac), Ir(mpyp)$_3$, or the like, but are not limited thereto.



Ir(ppy)$_3$



Ir(ppy)$_2$(acac)



Ir(mpyp)$_3$

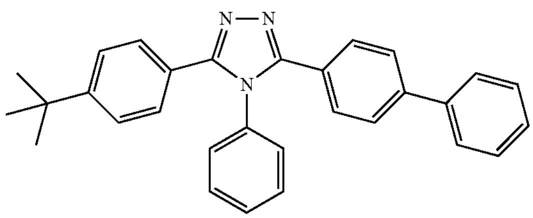
When the EML includes both a host and a dopant, the amount of the dopant may be from about 0.01 to about 15 parts by weight based on 100 parts by weight of the host. However, the amount of the dopant is not limited to this range.

The thickness of the EML may be about 200 Å to about 700 Å. When the thickness of the EML is within these ranges, the EML may have good light-emitting ability without a substantial increase in driving voltage.

Then, an ETL may be formed on the EML or a hole blocking layer (HBL) by any of a variety of methods, for example, vacuum deposition, spin coating, or casting. When the ETL is formed using vacuum deposition or spin coating, the deposition or coating conditions may be similar to those used to form the HIL, though the deposition or coating conditions may vary depending on the compound used to form the ETL.

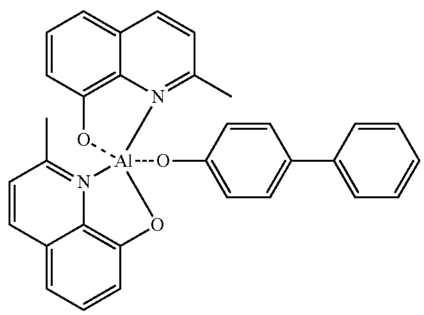
Any known electron transporting material that can stably transport electrons injected from an electron injecting electrode (cathode) may be used as the material for the ETL. Non-limiting examples of materials for forming the ETL include a quinoline derivative, such as tris(8-quinolinorate) aluminum (Alq3), TAZ, BAlq, beryllium bis(benzoquinolin-10-olate (Bebq2), 9,10-di(naphthylene-2-yl)anthracene (ADN), Compound 101, Compound 102, Bphen, or the like.

<compound 101>



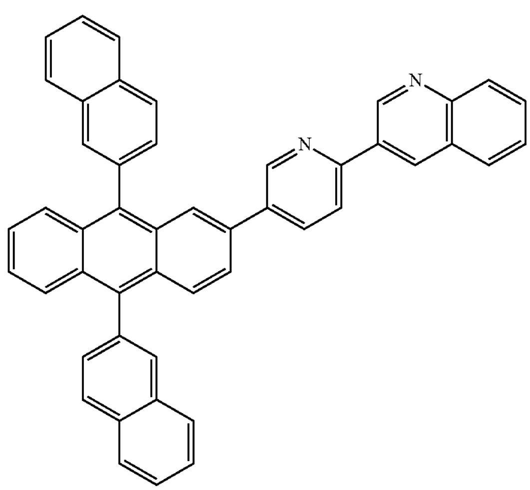
TAZ

<compound 102>

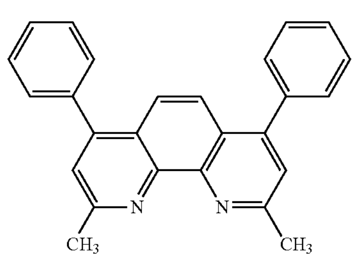


BAlq

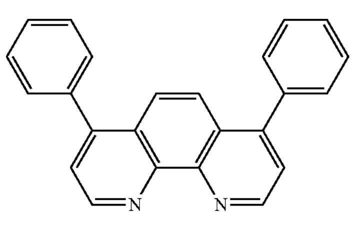
Error! Objects cannot be created from editing field codes.



BCP



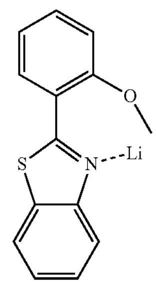
Bphen



A thickness of the ETL may be from about 100 Å to about 1,000 Å, and in some embodiments, may be from about 150 Å to about 500 Å. When the thickness of the ETL is within these ranges, the ETL may have satisfactory electron transporting ability without a substantial increase in driving voltage.

In some embodiments, the ETL may further include a metal-containing material in addition to the electron-transporting organic compound. The metal-containing material may include a lithium (Li) complex. Non-limiting examples of the Li complex may be lithium quinolate (LiQ) or Compound 203 below.

<compound 203>



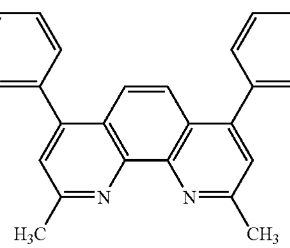
Then, an EIL, which facilitates injection of electrons from the cathode, may be formed on the ETL. Any suitable electron-injecting material may be used to form the EIL.

Non-limiting examples of the material for forming the EIL include LiF, NaCl, CsF, Li_2O, and BaO. The deposition or coating conditions for forming the EIL may be similar to those for the formation of the HIL, though the deposition or coating conditions may vary according to the material used to form the EIL.

A thickness of the EIL may be from about 1 Å to about 100 Å, and in some embodiments, may be from about 3 Å to about 90 Å. When the thickness of the EIL is within these ranges, the EIL may have satisfactory electron injection ability without a substantial increase in driving voltage.

A second electrode **17** may be disposed on the organic layer **15**. The second electrode **17** may be a cathode, which is an electron injection electrode. Here, the second electrode-forming material may be a metal, an alloy, an electro-conductive compound (which are materials having a low work function), or a mixture thereof. In this regard, the second electrode **16** may be formed as a transmission electrode using lithium (Li), magnesium (Mg), aluminum (Al), aluminum-lithium (Al—Li), calcium (Ca), magnesium-indium (Mg—In), magnesium-silver (Mg—Ag), or the like. In some embodiments, in order to manufacture a top-emission light-emitting diode, the transmission electrode may be formed of indium tin oxide (ITO) or indium zinc oxide (IZO).

Also, when a phosphorescent dopant is used in the EML, an HBL may be formed between the HTL and the EML, or between the H-functional layer and the EML to prevent triplet excitons or holes from dispersing into the electron transport layer. The HBL may be deposited by vacuum deposition, spin coating, casting, LB deposition, or the like. When the HIL is formed by vacuum deposition or spin coating, the deposition or coating conditions may be similar to those used to form the HIL, though the conditions for deposition or coating may vary depending on the compound used to form the HIL. A known hole blocking material may also be used, and examples thereof include an oxadiazole derivative, a triazole derivative, a phenanthroline derivative, or the like. For example, BCP may be used as the hole blocking material.



BCP

A thickness of the HBL may be from about 20 Å to about 1000 Å, and in some embodiments, may be from about 30 Å to about 300 Å. When the thickness of the EIL is within these ranges, the EIL may have satisfactory hole blocking ability without a substantial increase in driving voltage.

Although the organic light-emitting device 10 of FIG. 1 is described above, the present invention is not limited thereto.

The unsubstituted C_1-C_{60} alkyl group refers to linear or a branched alkyl group having from 1 to 60 carbon atoms, for example, methyl, ethyl, propyl, isobutyl, sec-butyl, pentyl, isoamyl, hexyl, and the like. The substituted C_1-C_{60} alkyl group refers to the substitution of at least one hydrogen atom of the unsubstituted C_1-C_{60} alkyl group with at least one of a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{60} alkyl group, a C_1-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group; a C_3-C_{10} cycloalkyl group, a C_2-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_2-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, or a C_2-C_{60} heteroaryl group substituted with at least one of a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, or a phosphoric acid group or a salt thereof; a C_3-C_{10} cycloalkyl group, a C_2-C_{10} heterocycloalkyl group, a C_3-C_{10} cycloalkenyl group, a C_2-C_{10} heterocycloalkenyl group, a C_6-C_{60} aryl group, a C_6-C_{60} aryloxy group, a C_6-C_{60} arylthio group, or a C_2-C_{60} heteroaryl group substituted with at least one of a deuterium atom, a halogen atom, a hydroxyl group, a cyano group, a nitro group, an amino group, an amidino group, a hydrazine, a hydrazone, a carboxylic acid group or a salt thereof, a sulfonic acid group or a salt thereof, a phosphoric acid group or a salt thereof, a C_1-C_{60} alkyl group, a C_2-C_{60} alkenyl group, a C_2-C_{60} alkynyl group, a C_1-C_{60} alkoxy group, a phenyl group, a naphthyl group, an anthryl group, a fluorenyl group, a dimethylfluorenyl group, a diphenyl fluorenyl group, a carbazolyl group, a phenylcarbazolyl group, a pyridyl group, a pyrimidyl group, a pyrazinyl group, a pyridazinyl group, a triazinyl group, a quinolyl group, or an isoquinolyl group; or —N(Q_{11})(Q_{12}); or —Si(Q_{13})(Q_{14})(Q_{15}) (where Q_{11} and Q_{12} are each independently a C_1-C_{60} alkyl group, a C_1-C_{60} alkoxy group, a C_6-C_{60} aryl group, or a C_2-C_{60} heteroaryl group).

In the present specification, the unsubstituted C_1-C_{60} alkoxy group (or C_1-C_{60} alkoxy group) is represented by —OA where A is an unsubstituted C_1-C_{60} alkyl group as described above. Examples of the unsubstituted C_1-C_{60} alkoxy group include a methoxy, an ethoxy, an isopropyloxy, or the like. The substituted C_1-C_{60} alkoxy group refers to the substitution of at least one hydrogen atom of the alkoxy group with the substituents described above in connection with the substituted C_1-C_{60} alkyl group.

In the present specification, the unsubstituted C_2-C_{60} alkenyl group (or C_2-C_{60} alkenyl group) refers to a group including at least one carbon-carbon double bond in the middle or at the end of the unsubstituted C_2-C_{60} alkenyl group. Examples thereof include an ethenyl, a propenyl, a butenyl, or the like. The substituted C_2-C_{60} alkenyl group refers to the substitution of at least one hydrogen atom of the C_2-C_{60} alkenyl group with the substituents described above in connection with the substituted C_1-C_{60} alkyl group.

In the present specification, the unsubstituted C_2-C_{60} alkynyl group (or C_2-C_{60} alkynyl group) refers to a group including at least one carbon-carbon triple bond in the middle or at the end of the C_2-C_{60} alkynyl group. Examples thereof include an ethynyl, a propenyl, or the like. The substituted C_2-C_{60} alkynyl group refers to the substitution of at least one hydrogen atom of the C_2-C_{60} alkynyl group with the substituents described above in connection with the substituted C_1-C_{60} alkyl group.

In the present specification, the unsubstituted C_3-C_{30} cycloalkyl group refers to a cyclic saturated monovalent hydrocarbon having from 3 to 60 carbon atoms. Examples thereof include a cyclopropyl, a cyclobutyl, a cyclopentyl, a cyclohexyl, a cyclooctyl, or the like. The substituted C_3-C_{30} cycloalkyl group refers to the substitution of at least one hydrogen atom of the cycloalkyl group with the substituents described above in connection with the substituted C_1-C_{60} alkyl group.

The unsubstituted C_3-C_{30} cycloalkenyl group refers to a group having at least one carbon-carbon double bond and an unsaturated hydrocarbon ring that is not an aromatic ring. Examples of the unsubstituted C_3-C_{30} cycloalkenyl group include a cyclopropenyl, a cyclobutenyl, a cyclopentenyl, a cyclohexenyl, a cycloheptenyl, a 1,3-cyclohexadienyl group, a 1,4-cyclohexadienyl group, a 2,4-cycloheptadienyl group, a 1,5-cyclooctadienyl group, or the like. The substituted C_3-C_{30} cycloalkenyl group refers to the substitution of at least one hydrogen atom of the cycloalkenyl group with the substituents described above in connection with the substituted C_1-C_{60} alkyl group.

The unsubstituted C_6-C_{60} aryl group refers to a monovalent group having a carbocyclic aromatic system having 6 to 60 carbon atoms including at least one aromatic ring. The unsubstituted C_6-C_{60} arylene group refers to a divalent group having a carbocyclic aromatic system having 6 to 60 carbon atoms including at least one aromatic ring. When the aryl group and the arylene group have at least two rings, they may be fused to each other. The substituted C_6-C_{60} aryl group and C_6-C_{60} arylene group refer to the substitution of at least one hydrogen atom of the aryl group or the arylene group with the substituents described above in connection with the C_1-C_{60} alkyl group.

Examples of the substituted or unsubstituted C_6-C_{60} aryl group include a phenyl group, a C_1-C_{10} alkylphenyl group (e.g., an ethylphenyl group), a C_1-C_{10} alkylbiphenyl group (e.g., an ethylbiphenyl group), a halophenyl group (e.g., an o-, m- or p-fluorophenyl group or a dichlorophenyl group), a dicyanophenyl group, a trifluoromethoxyphenyl group, an o-, m- or p-tolyl group, an o-, m- or p-cumenyl group, a mesityl group, a phenoxyphenyl group, an (α,α-dimethylbenzene)phenyl group, an (N,N'-dimethyl)aminophenyl group, an (N,N'-diphenyl)aminophenyl group, a pentalenyl group, an indenyl group, a naphthyl group, a halonaphthyl group (e.g., a fluoronaphthyl group), a C_1-C_{10} alkylnaphthyl group (e.g., a methylnaphthyl group), a C_1-C_{10} alkoxynaphthyl group (e.g., a methoxynaphthyl group), an anthracenyl group, an azulenyl group, a heptalenyl group, an acenaphthylenyl group, a phenalenyl group, a fluorenyl group, an anthraquinolyl group, a methylanthryl group, a phenanthryl group, a triphenylenyl group, a pyrenyl group, a chrysenyl group, an ethyl-chrysenyl group, a picenyl group, a perylenyl group, a chloroperylenyl group, a pentaphenyl group, a pentacenyl group, a tetraphenylenyl group, a hexaphenyl group, a hexacenyl group, a rubicenyl group, a coronenyl group, a trinaphthylenyl group, a heptaphenyl group, a heptacenyl group, a pyranthrenyl group, and an ovalenyl group. Examples of the substituted C_6-C_{60} aryl group may be inferred from the examples of the unsubstituted C_6-C_{60} aryl group and the substituted C_1-C_{60} alkyl group described above. Examples of the substituted and unsubstituted C_6-C_{60} arylene group may be inferred from the examples of the substituted and unsubstituted C_6-C_{60} aryl group described above.

The unsubstituted C_2-C_{60} heteroaryl group refers to a monovalent group having at least one aromatic ring having at least one heteroatom selected from N, O, P, and S. The unsubstituted C_2-C_{60} heteroarylene group may be a divalent group having at least one aromatic ring having at least one heteroatom selected from N, O, P, and S. Here, when the heteroaryl group or the heteroarylene group has at least two rings, they may be fused to each other. The substituted C_2-C_{60} heteroaryl group and C_2-C_{60} heteroarylene group refer to the substitution of at least one hydrogen atom of the heteroaryl group or the heteroarylene group with the substituents described with reference to the C_1-C_{60} alkyl group.

Examples of the unsubstituted C_2-C_{60} heteroaryl group include a pyrazolyl group, an imidazolyl group, an oxazolyl group, a thiazolyl group, a triazolyl group, a tetrazolyl group, an oxadiazolyl group, a pyridinyl group, a pyridazinyl group, a pyrimidyl group, a triazinyl group, a carbazolyl group, an indolyl group, a quinolinyl group, an isoquinolinyl group, a benzoimidazolyl group, an imidazopyridinyl group, an imidazopyrimidyl group, or the like. Examples of the substituted or unsubstituted C_6-C_{60} arylene group may be inferred from the examples of the substituted or unsubstituted C_2-C_{60} arylene group described above.

The substituted or unsubstituted C_6-C_{60} aryloxy group refers to a group represented by —OA_2 where A_2 is a substituted or unsubstituted C_6-C_{60} aryl group described above. The substituted or unsubstituted C_6-C_{60} arylthio group refers to a group represented by —SA_3 where A_3 is a substituted or unsubstituted C_6-C_{60} aryl group described above.

Hereinafter, the present invention will be described with reference to the following synthesis examples and other examples. However, these examples are presented for illustrative purposes only and are not intended to limit the scope of the present invention.

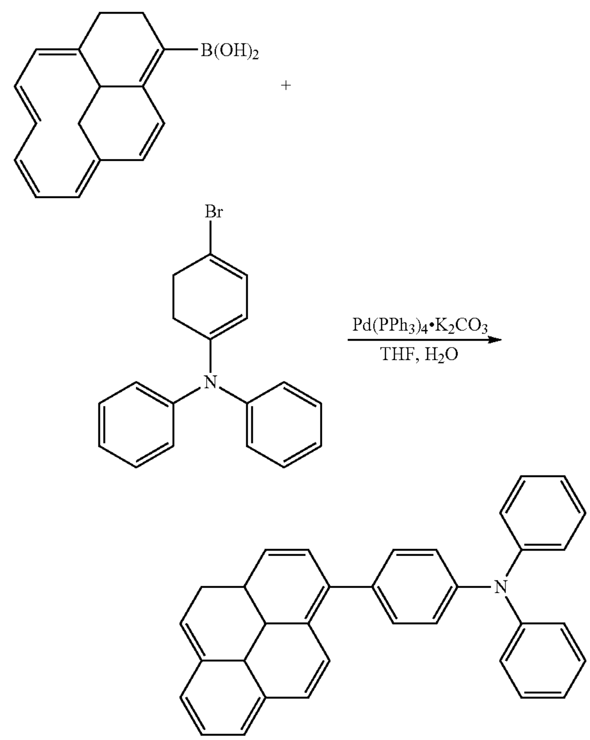
Example

Synthesis Example 1

Synthesis of Compound 1

Compound 1 was synthesized according to Reaction Scheme 1 below:

<Reaction Scheme 1>



A mixture of pyrene-1-boronic acid (0.75 g, 3.1 mmol), 4-bromo triphenyl amine (1 g, 3.1 mmol), 2M potassium carbonate 16 ml, and $Pd(PPh_3)_4$ (0.15 g, 0.09 mmol) in dimethoxy ethanol was refluxed under inert atmosphere for 15 h. After cooling at room temperature, the solvent was evaporated in vacuum and the residue was dissolved in dimethylchloride. The organic phase was washed with distilled water, and moisture was removed by drying with Na_2SO_4. The solvent was removed to obtain a crude product. The crude product was then subjected to column chromatography using dimethyl chloride, ethyl acetate, and methanol as eluents to obtain Compound 1 (1.19 g, yield rate 85%). Compound 1 was observed through ^1H NMR, ^{13}C NMR, MALDI-TOF MS, and HRMS (FAB).

^1H NMR (300 MHz, DMSO-d6): δ=(ppm) 8.32 (q, 6 Hz, 4H), 8.21 (q, 3 Hz, 4H), 8.11-8.02 (m, 2H), 7.53 (d, 9 Hz 2H), 7.38 (t, 6 Hz, 4H), 7.19-7.08 (m, 7H).

^{13}C NMR (125 MHz, DMSO): δ=(ppm) 147.08, 146.66, 136.74, 134.02, 131.34, 130.98, 130.43, 129.90, 129.67, 127.63, 127.57, 127.36. 127.27, 126.37, 125.25, 124.96, 124.88, 124.71, 124.36, 124.23, 124.09, 123.99, 123.37, 122.67

MALDI-TOF MS: $C_{34}H_{23}N$, estimated value 445.18 g/mol, measured value 445.27 g/mol.

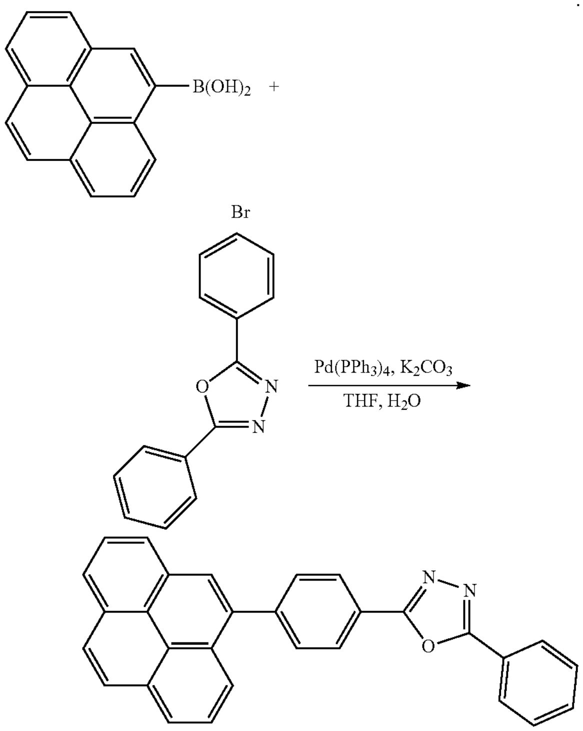
HRMS (FAB): $C_{34}H_{23}N$, estimated value 445.1830 g/mol, measured value 445.1833 g/mol.

Synthesis Example 2

Synthesis of Compound 15

Compound 15 was synthesized according to Reaction Scheme 1 below:

<Reaction Scheme 2>



A mixture of pyrene-1-boronic acid (0.8 g, 3.3 mmol), 2-(4-Bromo-phenyl)-5-phenyl-[1,3,4]oxadiazole (1 g, 3.3 mmol), 2M potassium carbonate 20 ml, and $Pd(PPh_3)_4$ (0.156 g, 0.1 mmol) in dimethoxy ethanol was refluxed under an inert atmosphere for 15 h. After cooling at room temperature, the solvent was evaporated in vacuum and the residue was dissolved in dimethylchloride. The organic phase was washed with distilled water, and moisture was removed by drying with Na_2SO_4. The solvent was removed to obtain a crude product. The crude product was then subjected to column chromatography using dimethyl chloride, ethyl acetate, and methanol as eluents to obtain Compound 15 (1.14 g, yield rate 81%). Compound 15 was observed through ^1H NMR, ^{13}C NMR, MALDI-TOF MS, and HRMS (FAB).

^1H NMR (300 MHz, DMSO-d6): δ=(ppm) 7.97 (d, 6 Hz, 2H), 7.84 (q, 6 Hz, 2H), 7.76-7.73 (m, 2H), 7.49 (d, 9 Hz 2H), 7.24-7.20 (m, 3H), 7.11-7.01 (m, 4H), 6.89 (t, 6 Hz, 2).

^{13}C NMR (125 MHz, DMSO): δ=(ppm) 164.12, 164.02, 143.95, 135.74, 132.14, 131.38, 130.96, 130.61, 130.37, 129.49, 128.17, 127.82, 127.60, 127.37, 127.02, 126.88, 126.76, 126.57, 125.65, 125.25, 125.05, 124.23, 124.15, 123.97, 123.42, 122.39

MALDI-TOF MS: $C_{30}H_{18}N_2O$, estimated value 422.14 g/mol, measured value 422.26 g/mol.

HRMS (FAB): $C_{30}H_{18}N_2O$, estimated value 422.1419 g/mol, measured value 422.1420 g/mol.

Example 1

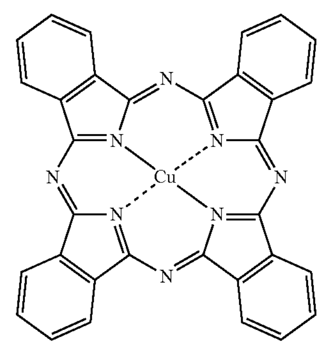
As an anode, a Corning 15 Ω/cm^2 (1200 Å) ITO glass substrate was cut into a size of 50 mm×50 mm×0.7 mm, ultrasonically washed for 5 minutes using isopropyl alcohol and distilled water, irradiated with ultraviolet rays for 30 minutes, and washed by exposure to ozone for 10 minutes. The glass substrate was installed on a vacuum deposition device.

Phthalocyanine (CuPc) was vacuum deposited on top of the ITO glass substrate to form an HIL having a thickness of 1000 Å. On the HIL, N,N'-bis(naphthylene-1-yl)-N,N'-bis (phenyl)-benzidine (NPB) was vacuum deposited to form an HTL having a thickness of 700 Å.

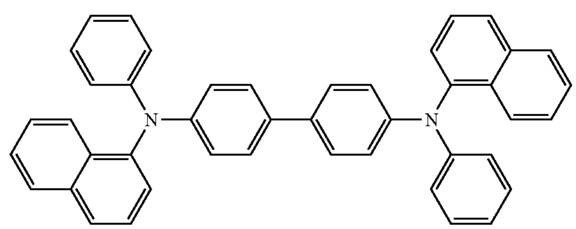
Compound 1 was vacuum deposited on the HTL to form a first emission layer having a thickness of 300 Å. Compound 15 was vacuum deposited on the first emission layer to form a second emission layer having a thickness of 100 Å.

Bis(2-methyl-8-quinolate-4-(phenylpenolato)aluminum (BAlq) was vacuum deposited on the second emission layer to form an HTL having a thickness of 200 Å, 8-hydroxyquinolinolato-lithium (LiQ) was vacuum deposited on the HTL to form an HIL having a thickness of 10 Å, and Al was vacuum deposited on the HIL to form a cathode having a thickness of 1000 Å, thereby completing the manufacture of an organic light-emitting device.

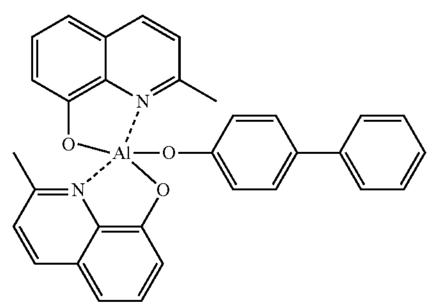
CuPc



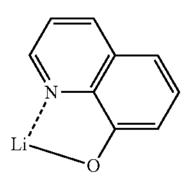
NPB



BAlq



LiQ



Example 2

An organic light-emitting device was manufactured as in Example 1, except that compound 1 and compound 15 were vacuum deposited in a weight ratio of 3:1 to form an emission layer having a thickness of 400 Å (instead of a first emission layer and a second emission layer).

Comparative Example 1

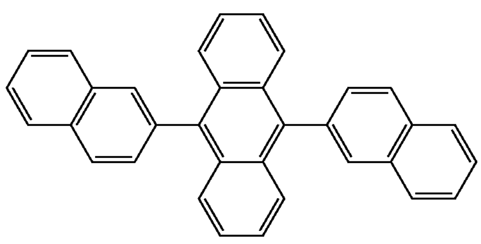
An organic light-emitting device was manufactured as in Example 1, except that compound 1 was vacuum to form an emission layer having a thickness of 400 Å (instead of a first emission layer and a second emission layer).

Comparative Example 2

An organic light-emitting device was manufactured as in Example 1, except that compound 15 was vacuum deposited to form an emission layer having a thickness of 400 Å (instead of a first emission layer and a second emission layer).

Comparative Example 3

An organic light-emitting device was manufactured in the same manner as in Example 1, except that compound 1 and ADN were vacuum deposited in a weight ratio of 3:1 to form an emission layer having a thickness of 400 Å (instead of a first emission layer and a second emission layer).



ADN

Evaluation Example 1

External quantum efficiencies, efficiencies, power efficiencies, EL maximum peaks, and color coordinates of the organic light-emitting devices of Examples 1 and 2 and Comparative Examples 1 to 3 were evaluated using a PR650 Spectroscan Source Measurement Unit (manufactured by PhotoResearch). The results are shown in Table 1.

TABLE 1

	Light-emitting materials				
	A first emission layer material	A second emission layer material	External quantum efficiency (%)	EL λ_{max} (nm)	Color coordinates
Comp. Example 1	compound 1		1.1	460	0.15, 0.13
Comp. Example 2	compound 15		1.2	472	0.17, 0.21
Comp. Example 3	compound 1:ADN = 3:1 (w/w)		0.8	458	0.14, 0.15

TABLE 1-continued

	Light-emitting materials				
	A first emission layer material	A second emission layer material	External quantum efficiency (%)	EL λ_{max} (nm)	Color coordinates
Example 1	compound 1	compound 15	2.8	468	0.15, 0.16
Example 2	compound 1:compound 15 = 3:1 (w/w)		3.5	472	0.15, 0.19

According to Table 1 above, the organic light-emitting device of Examples 1 and 2 have greater external quantum efficiencies than the organic light-emitting devices of Comparative Examples 1 to 3.

While the present invention has been illustrated and described with reference to certain exemplary embodiments, those of ordinary skill in the art will understand that various changes may be made to the described embodiments without departing from the spirit and scope of the present invention as defined by the following claims.

What is claimed is:

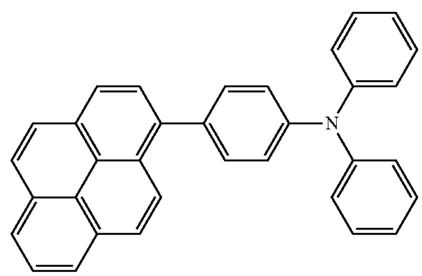
1. An organic light-emitting device comprising:

a first electrode;

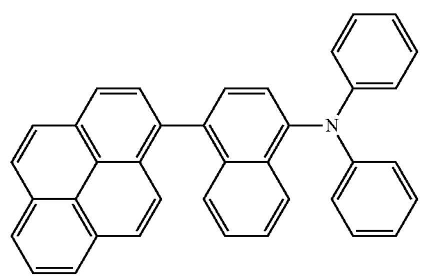
a second electrode; and

an organic layer between the first electrode and the second electrode, wherein the organic layer comprises an emission layer, the emission layer comprising at least one amine-based compound selected from Compounds 1 through 14 and at least one pyrene-based compound selected from one of Compounds 15 through 21:

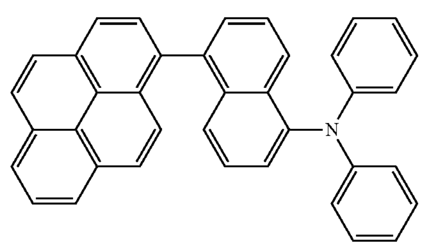
<Compound 1>



<Compound 2>



<Compound 3>



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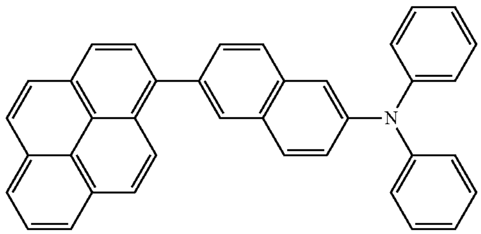
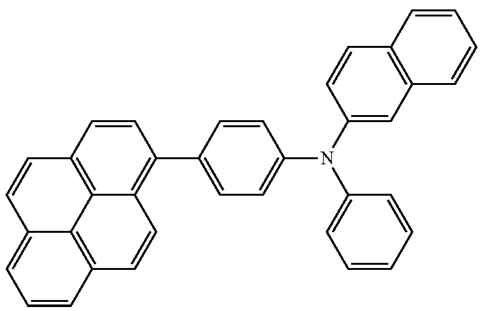
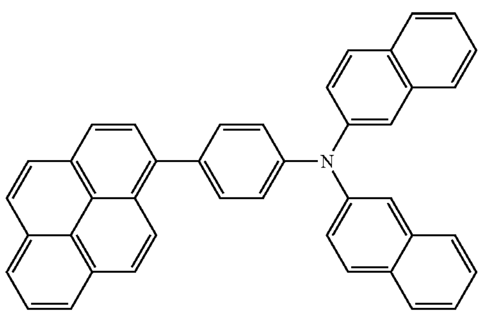
<Compound 4>



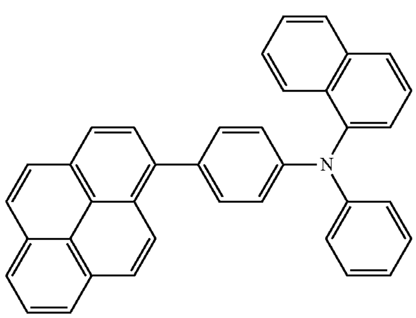
<Compound 5>



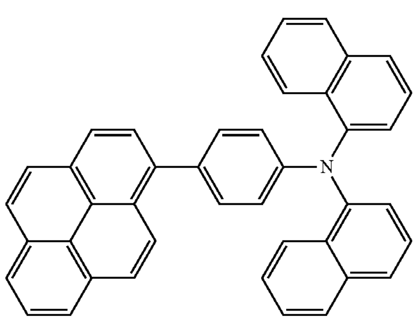
<Compound 6>



<Compound 7>



<Compound 8>



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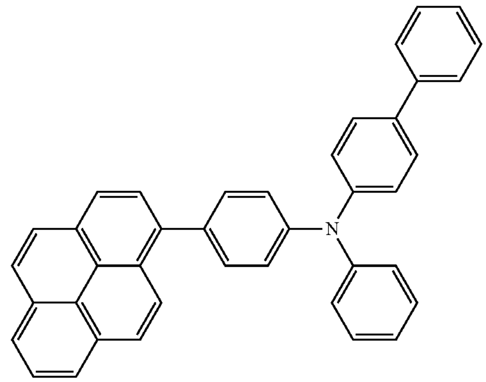
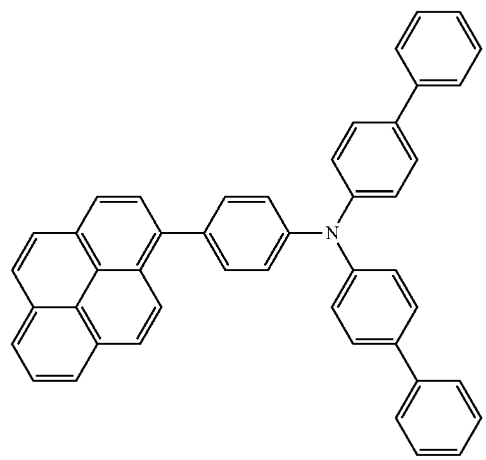
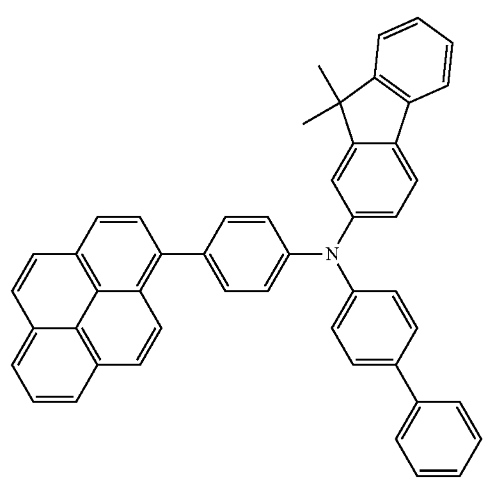
<Compound 9>



<Compound 10>



<Compound 11>



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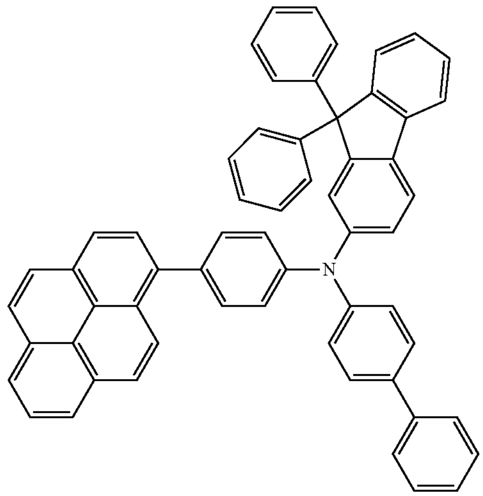
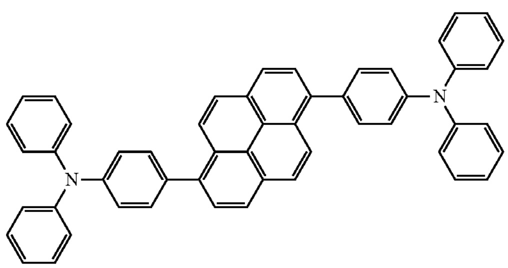
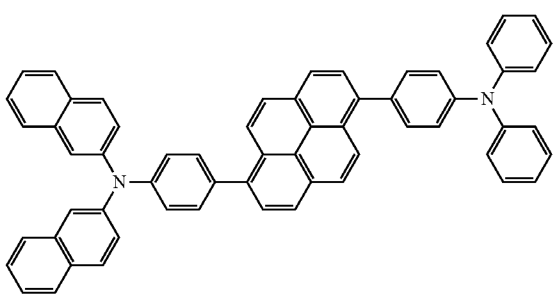
<Compound 12>



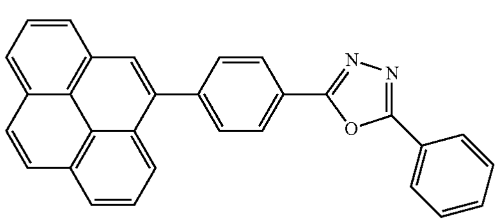
<Compound 13>



<Compound 14>



<Compound 15>



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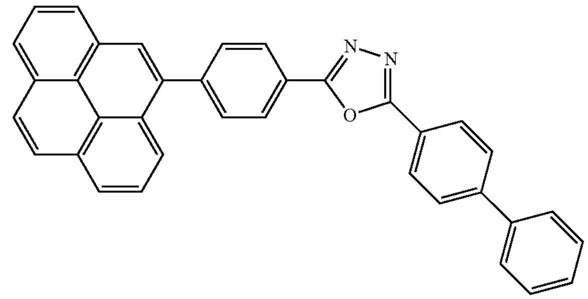
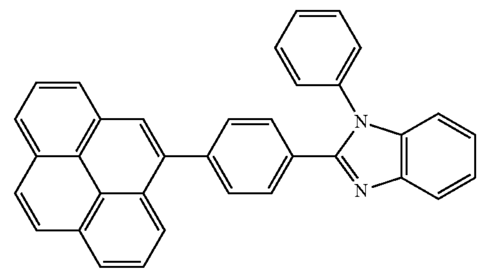
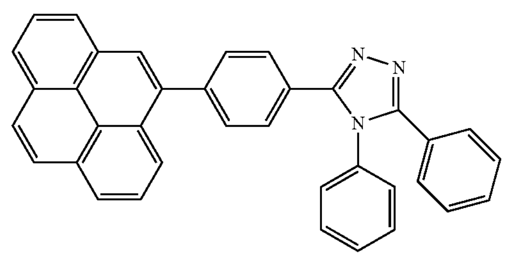
<Compound 16>



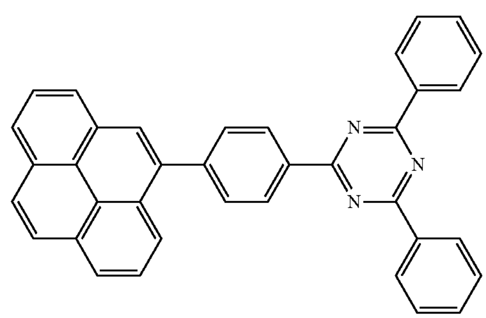
<Compound 17>



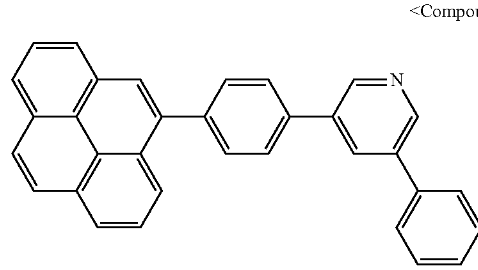
<Compound 18>



<Compound 19>



<Compound 20>



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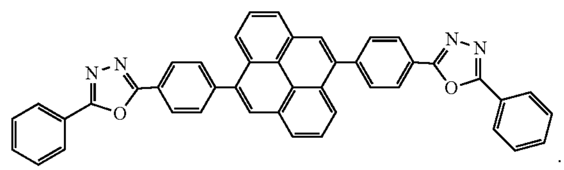
<Compound 21>



2. The organic light-emitting diode of claim 1, wherein the organic layer comprises:

a hole transport region between the first electrode and the emission layer and having at least one of a hole injection layer, a hole transport layer, a functional layer having both hole injection ability and hole transport ability, a buffer layer, and/or an electron blocking layer; and

an electron transport region between the emission layer and the second electrode and having at least one of a hole blocking layer, an electron transport layer, and/or an electron injection layer.

3. The organic light-emitting diode of claim 1, wherein the amine-based compound and the pyrene-based compound are co-deposited.

4. The organic light-emitting diode of claim 1, wherein the emission layer comprises a first emission layer and a second emission layer, and the first emission layer comprises the amine-based compound, and the second emission layer comprises the pyrene-based compound.

5. The organic light-emitting diode of claim 4, wherein the first emission layer is between the second emission layer and the first electrode.

* * * * *